The X-ray LHB

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With a great deal of help from my friends!

Basics

Astronomers and Physicists disagree:

- Transitions in O^{+7} produces lines labeled OVIII
- In charge exchange O^{+7} is the parent species producing OVII

Absorption: $\sigma \sim E^{-8/3}$

- the lower the photon energy, the more likely to be absorbed

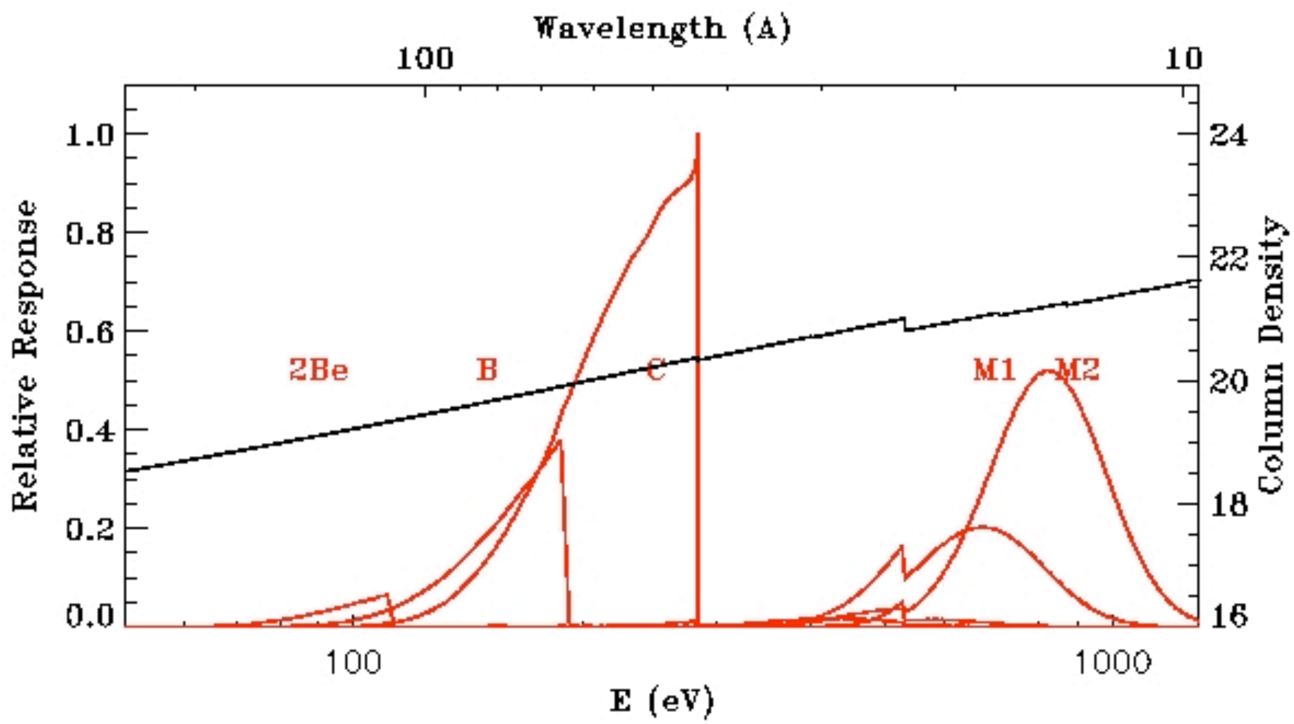
The X-ray Background (ca. 1960)

- Studied in 2-10 keV band (Giacconi 1962)
- Power law spectrum
- At lower energies should be entirely absorbed by the neutral H in the Galactic plane
- Observations revealed ¼ keV emission everywhere, including the Galactic plane

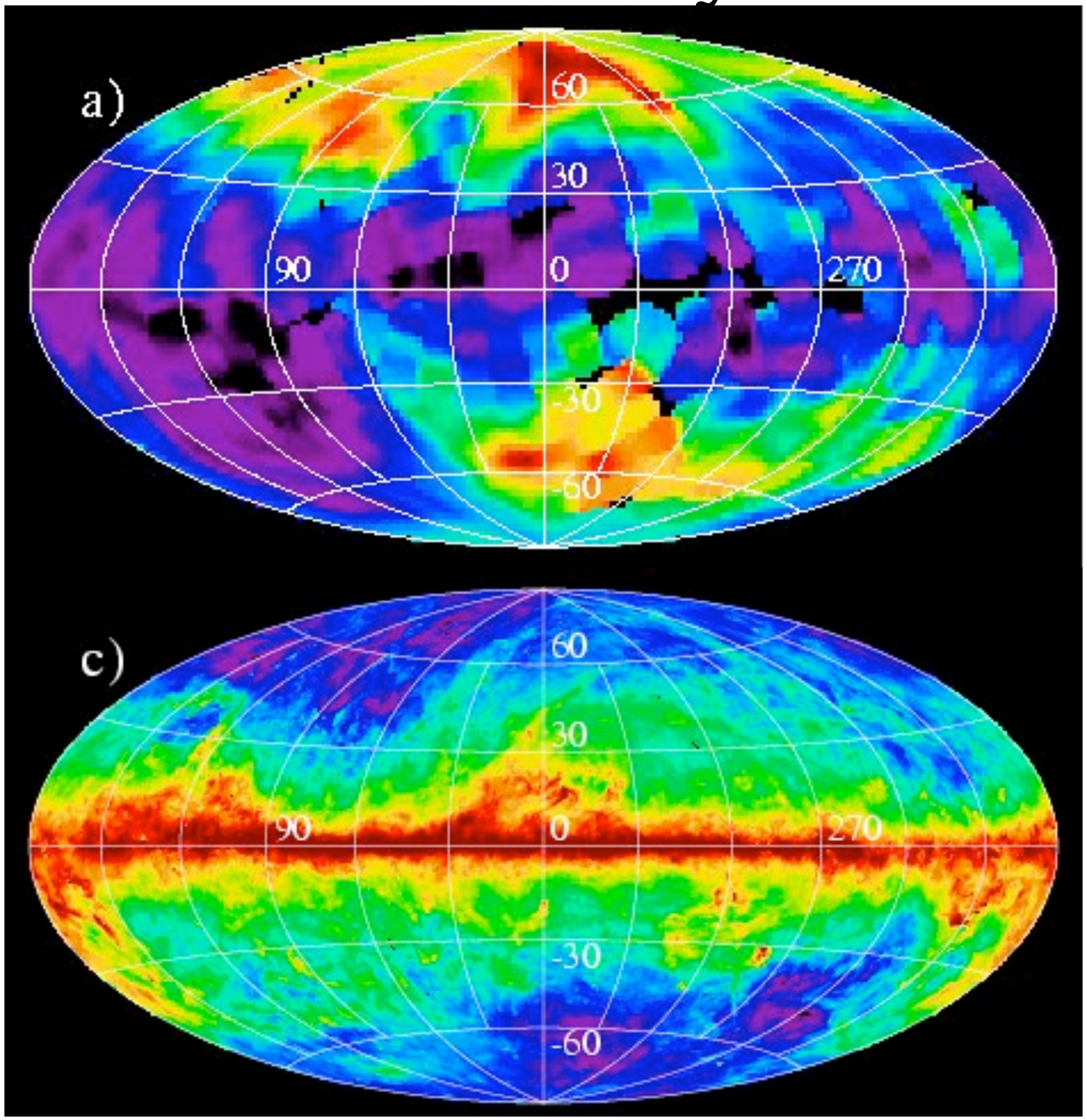
Bowyer et al.(1968), Henry et al.(1968), Bunner et al.(1968)

The fundamental surveys: Wisconsin

- All-sky rocket borne survey
- Executed 1972-1980
- 6.5° resolution
- In C band $\tau=2$ (15% trans.) at $n_H \sim 5\times10^{20}$ cm^{-2}
- Expect to see Gal. disk shadow extragalactic emission

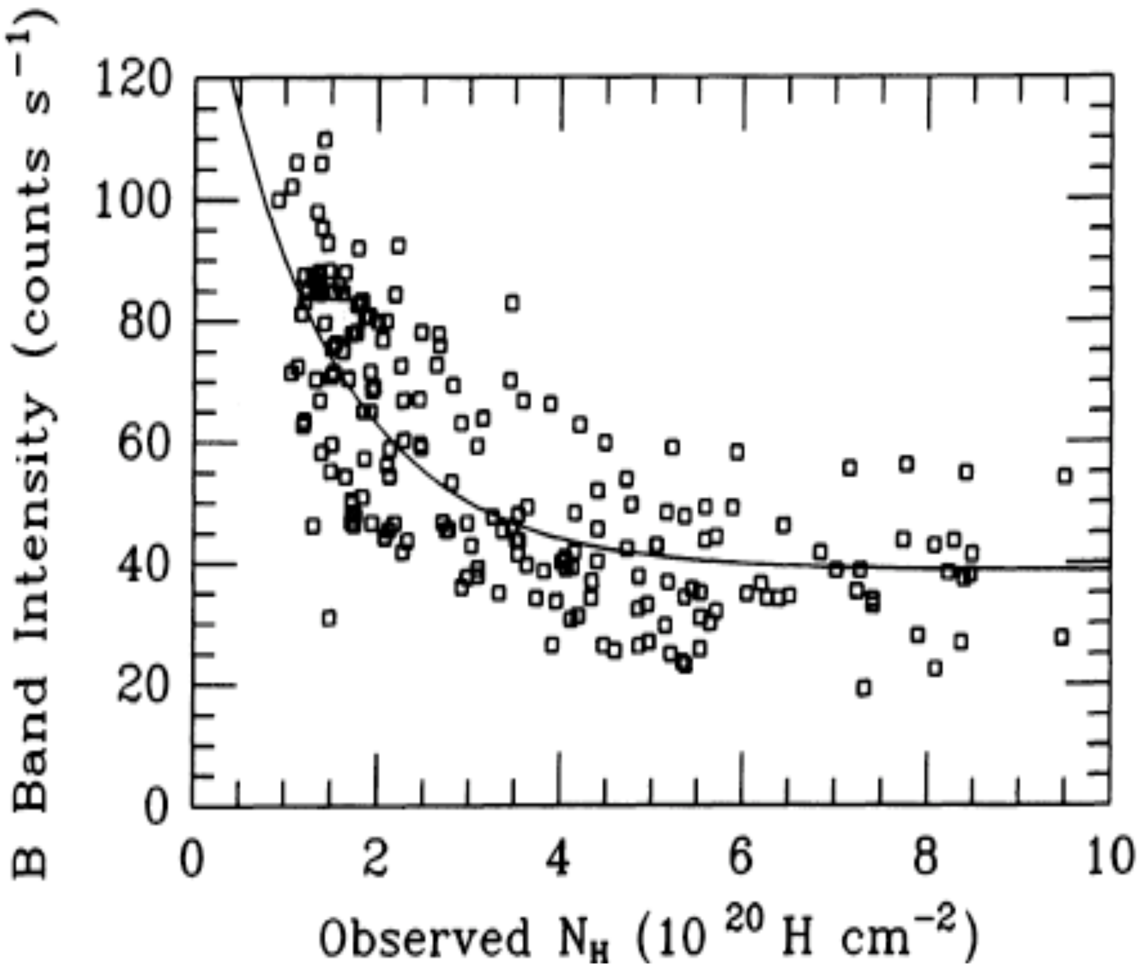


The fundamental surveys: Wisconsin



- No small scale shadows…

The fundamental surveys: Wisconsin



…large-scale anticorrelation in B band!

An Old Controversy

Assuming a uniform distribution of nH,

three ways of producing the anticorrelation:

1. Absorption - all emission extragalactic

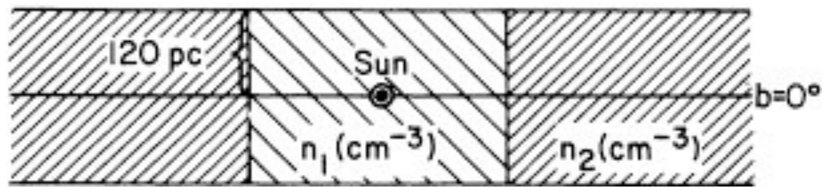
   Can’t work with reasonable cross-sections

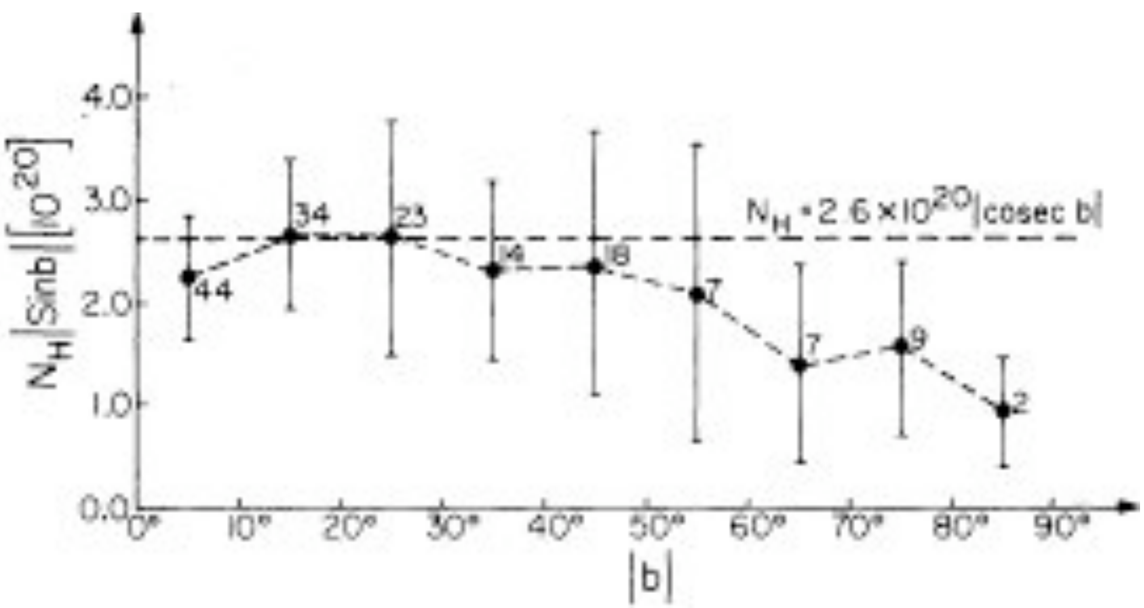
2. Displacement (cavity) - all emission local
3. Absorption and emission interleaved

The Local Cavity

Local ISM remarkably deficient in neutral gas

- Knapp (1975) from $n_H(b)$





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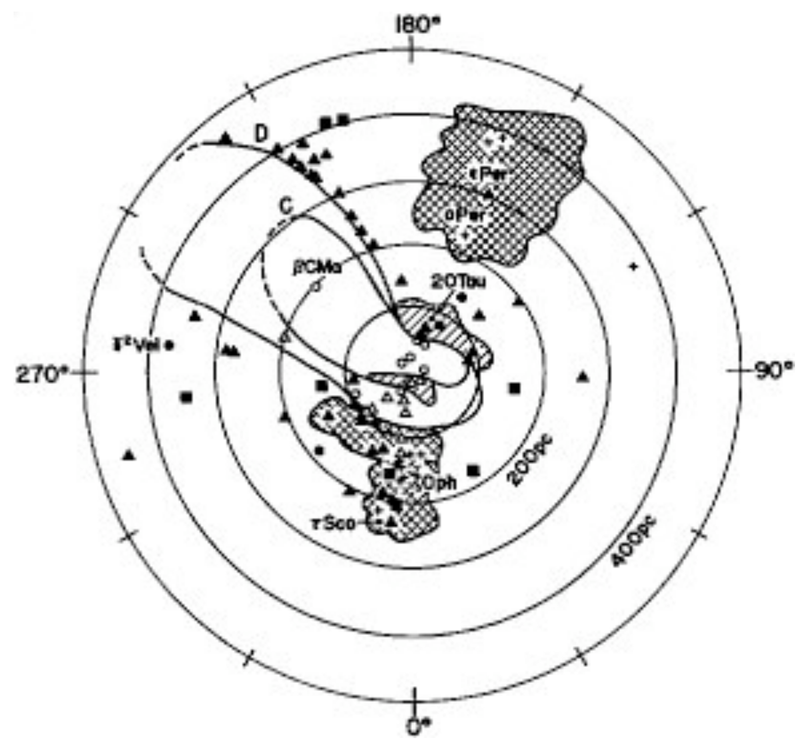

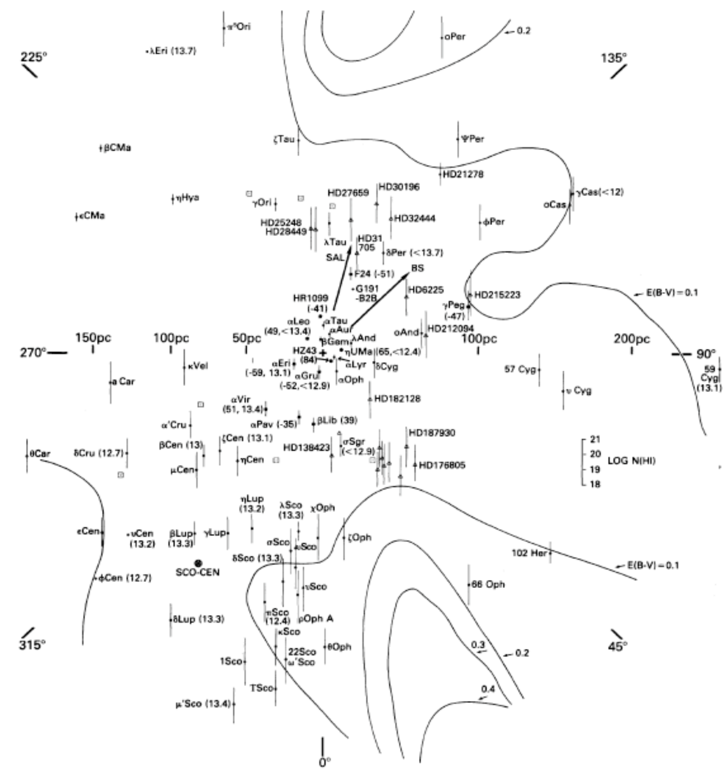

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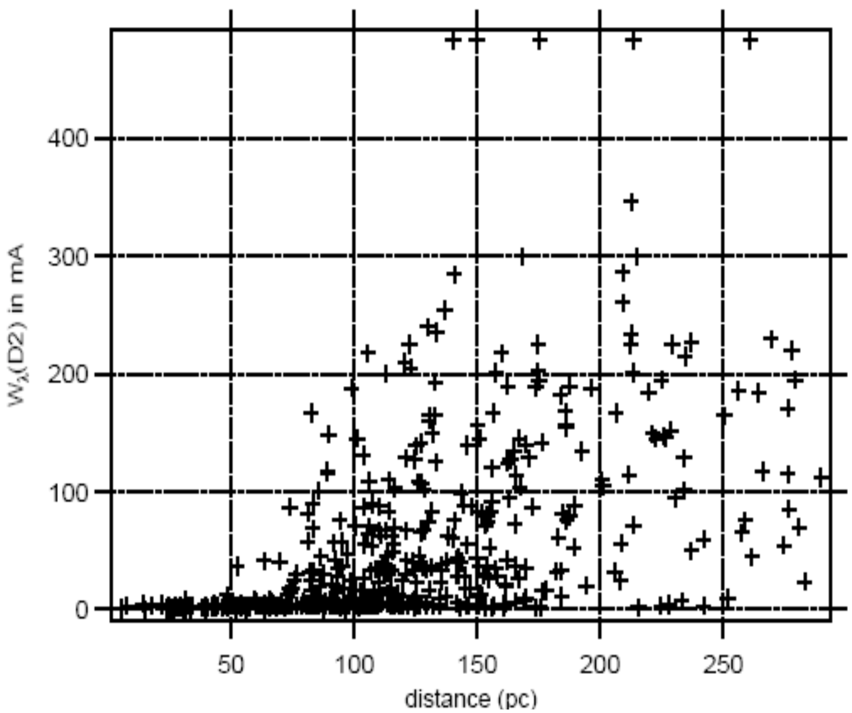
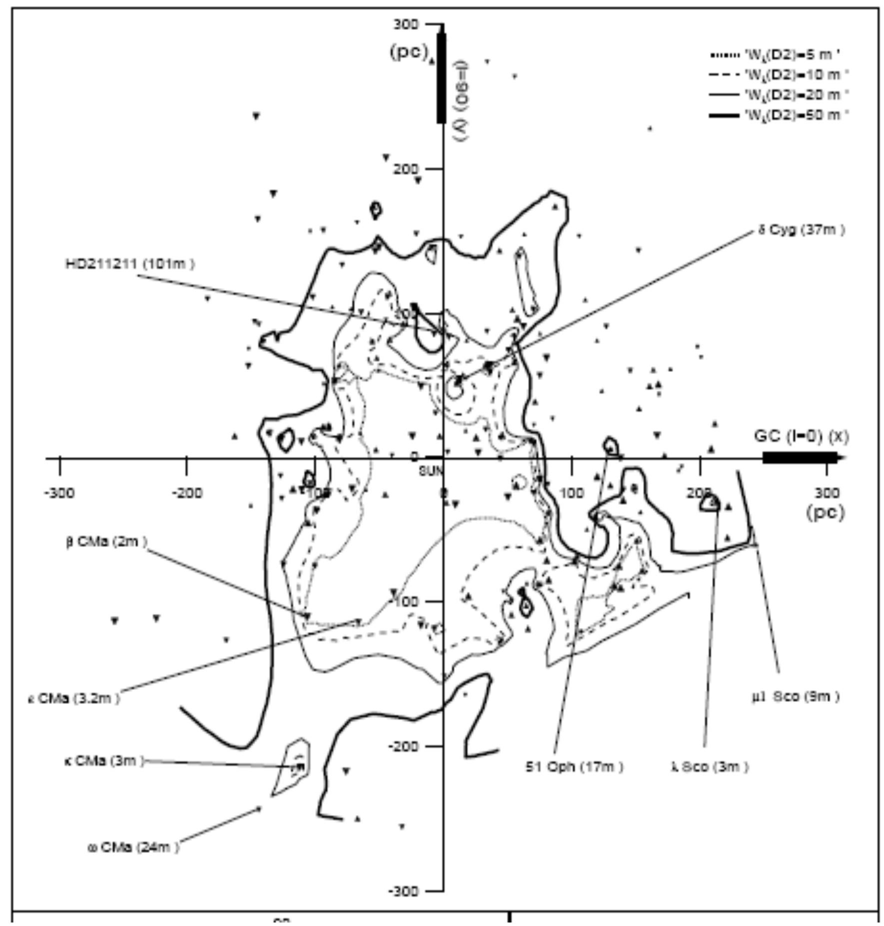
- Sfeir et al (1999)





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1. Absorption - all emission extragalactic
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   Fit well with local ISM knowledge
3. Absorption and emission interleaved

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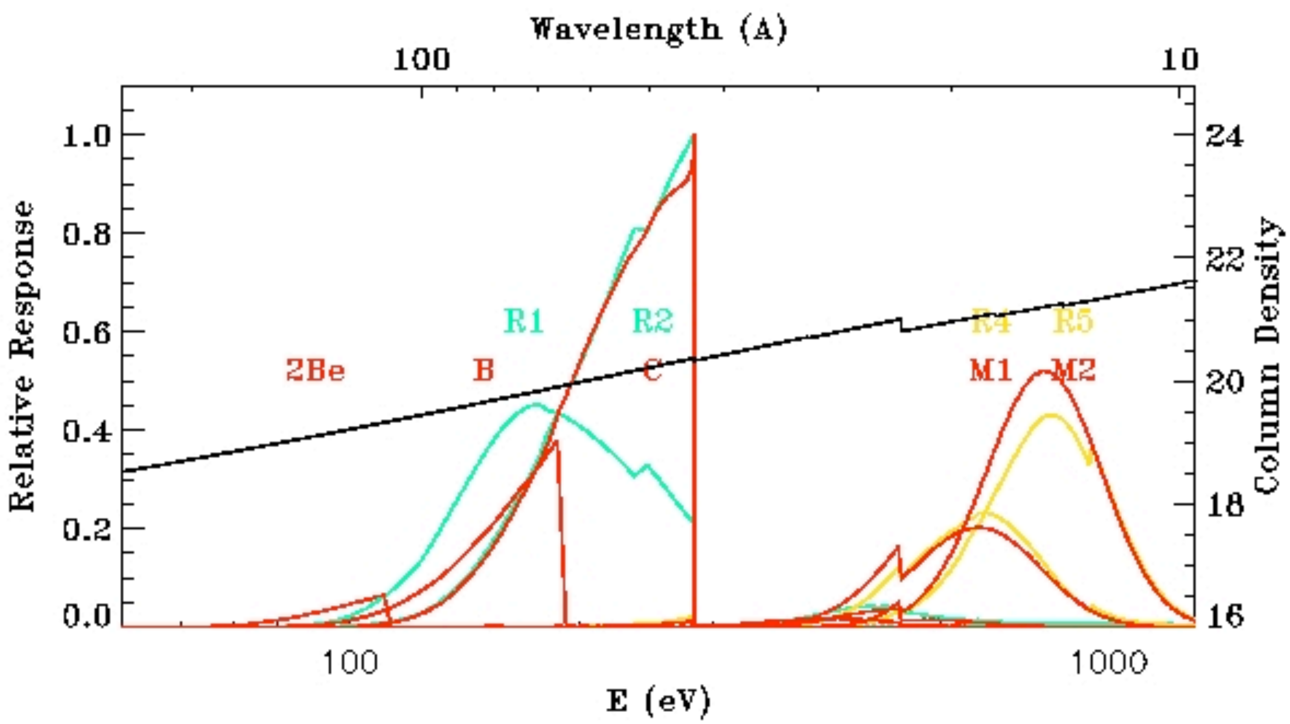
   Demonstrated by ROSAT

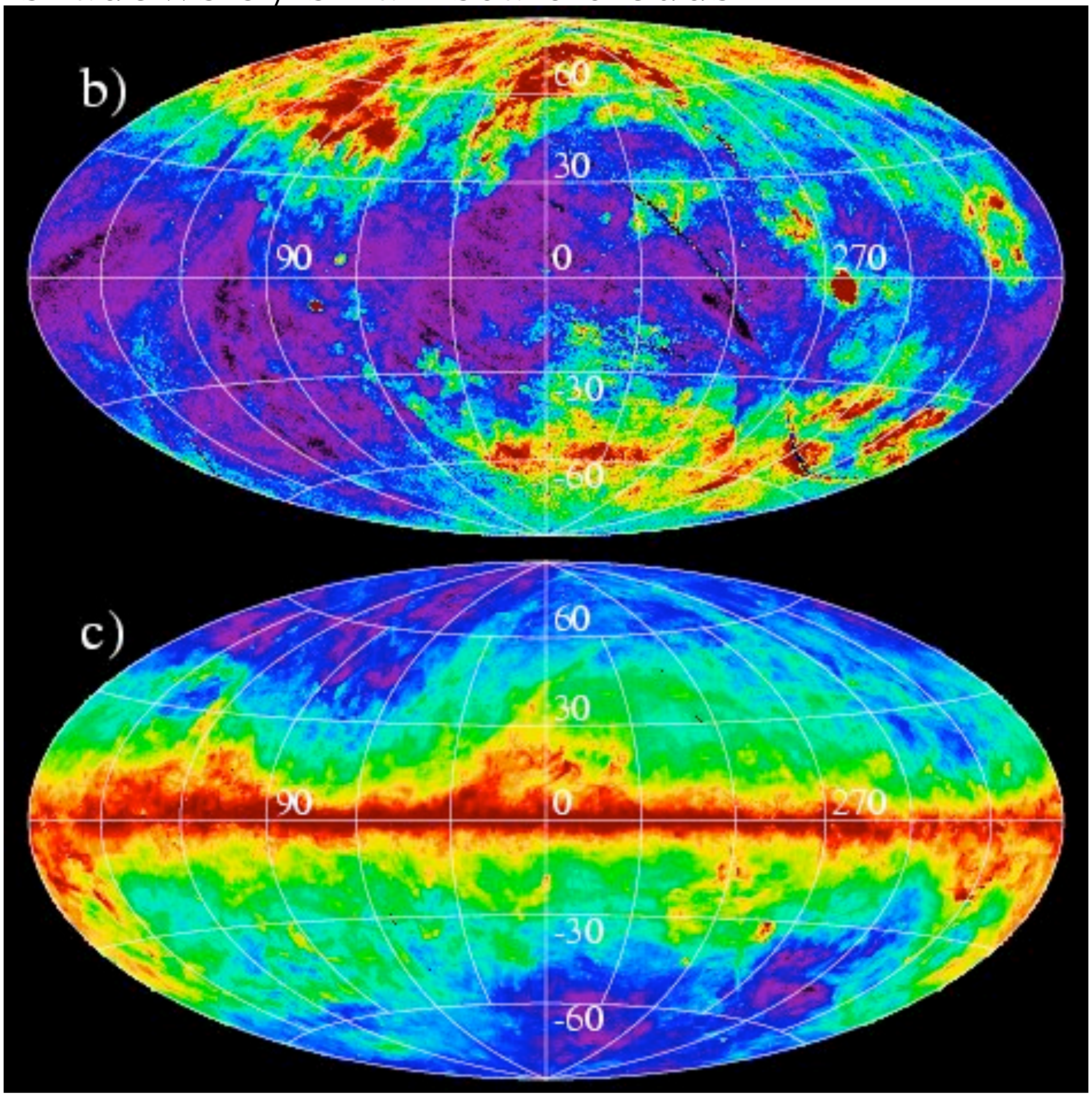
The fundamental surveys: ROSAT

- All-sky satellite borne survey
- Executed 1990-1991
- 12’ effective resolution



The fundamental surveys: ROSAT

- Lots of shadows by small-scale clouds



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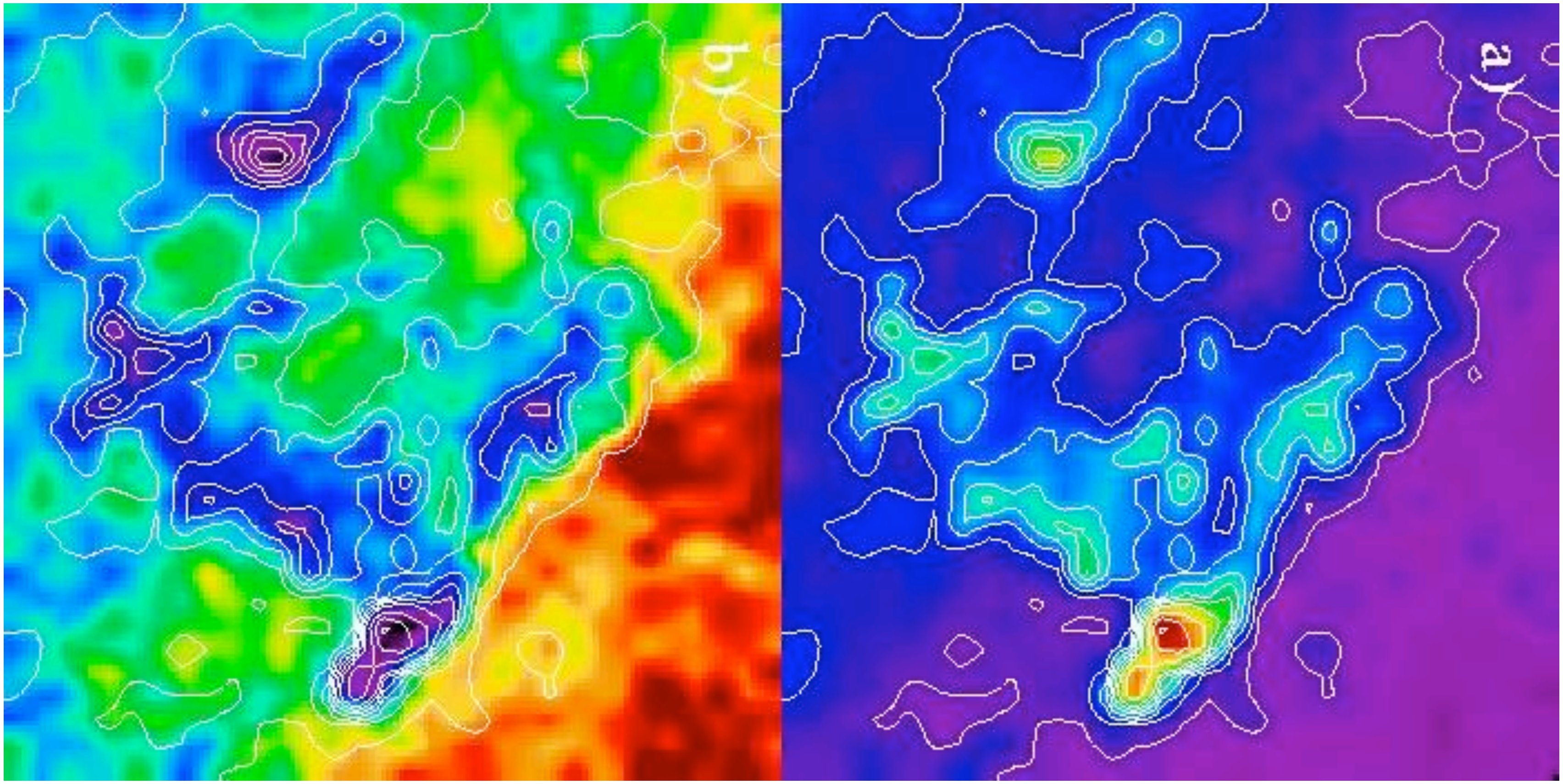
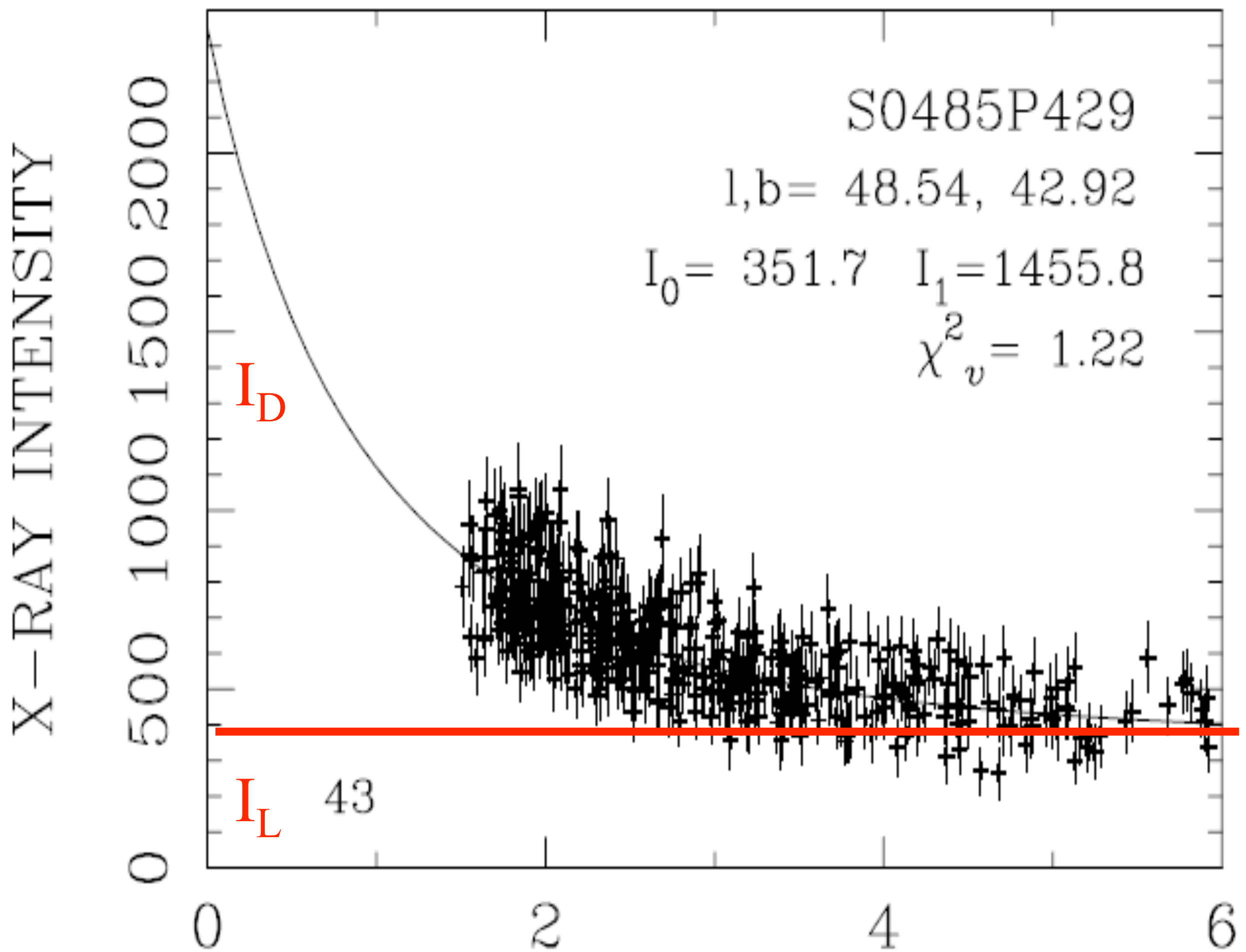


- Even the most opaque clouds show foreground emission

Isolating the Local Component

L/D Decomposition

- Assume background and foreground flat
- Plot I_X vs. n_H
- Fit $I_{obs}=I_L+I_D e^{(-\sigma n)}$



Isolating the Local Component

L/D Decomposition Caveats

- Flatness requires small area
- nH dynamic range requires large area
- Unreliable if multiple interleaved components
- Must know background spectrum to get σ_{eff}

Isolating the Local Component

- L/D Decomposition
  - C band – works well
  - M band (3/4 keV) – clouds not sufficiently opaque
- Observe at E such that Local Cavity walls are opaque
  - Be band and (to some extent) B band

Isolating the Local Component

What do we find?

- B/Be~constant $\rightarrow n_H <$ few $\times 10^{18}$ cm^{-2}
- C_L:B:Be or $R2_L$:$R1_L$ $\rightarrow$model$\rightarrow$kT~10^6K$\rightarrow\varepsilon$

  since R_{max} set by the Local Cavity size

$C_L = \int_0^R \varepsilon n_e n_i dV \rightarrow n_e \sim 0.002$

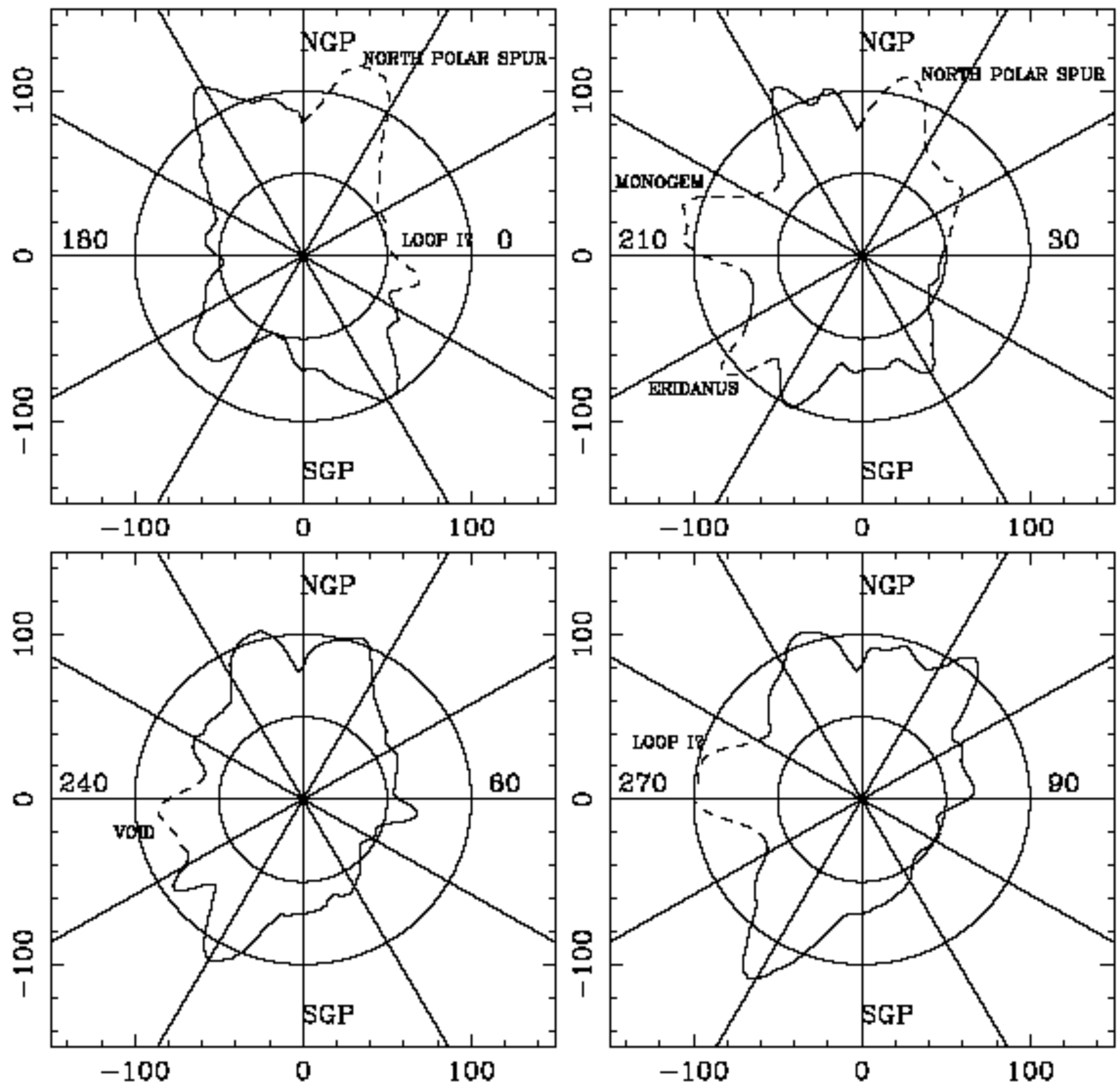
$\rightarrow$ P/k~1.5×10^4 cm^{-3}K & c_s~100 km/s

$\rightarrow$crossing time ~few$\times10^6$ yrs

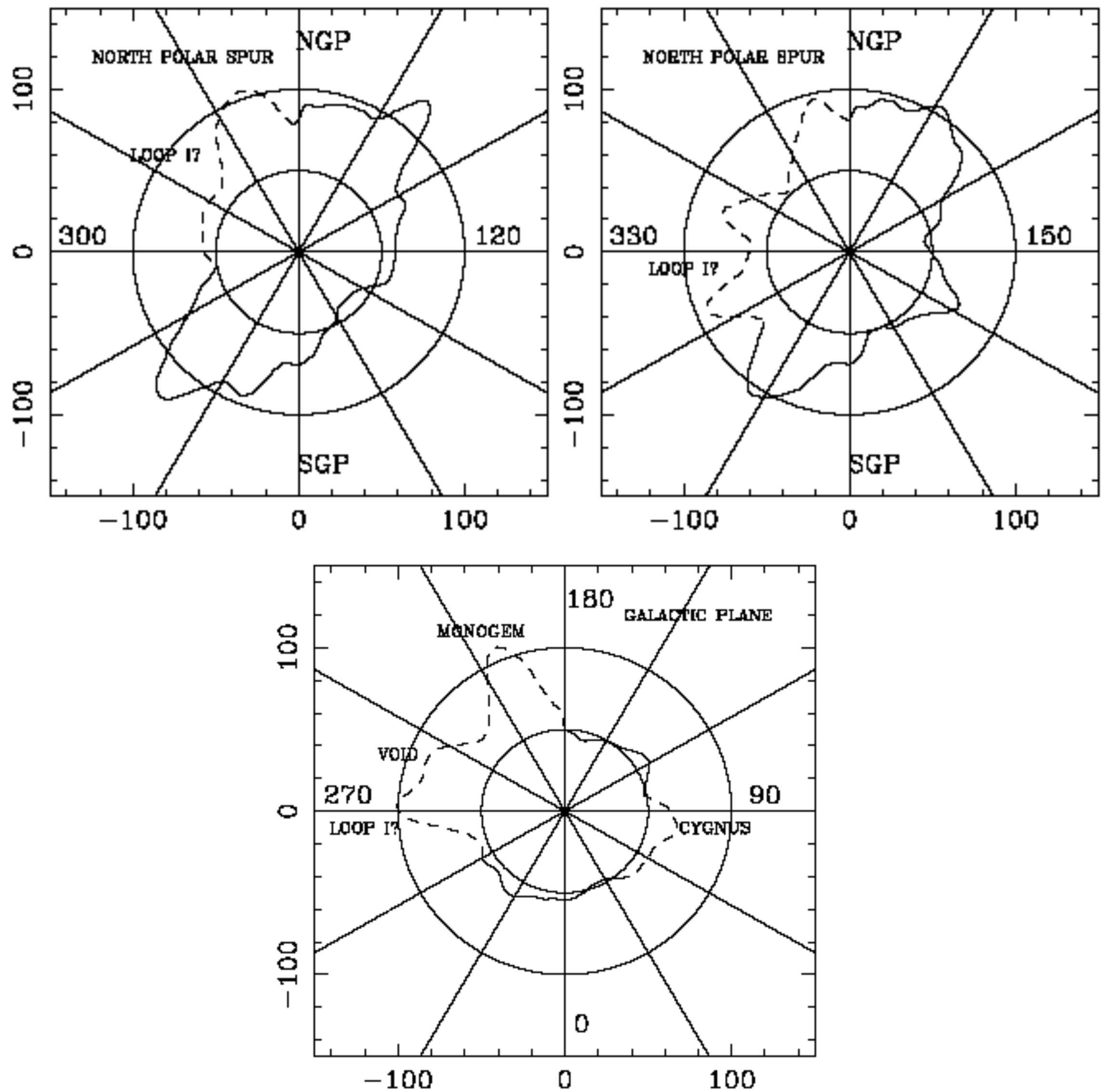
$\rightarrow$emitting region likely in equilibrium

$\rightarrow\varepsilon$ is the same everywhere and

$R_{emit}(l,b) = fI_L(l,b) \rightarrow$ shape of emitting region

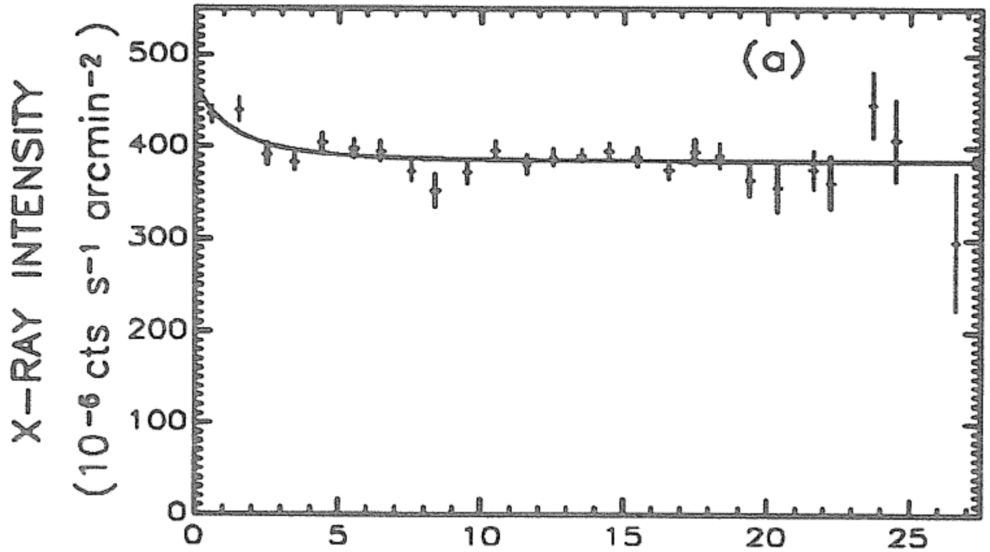


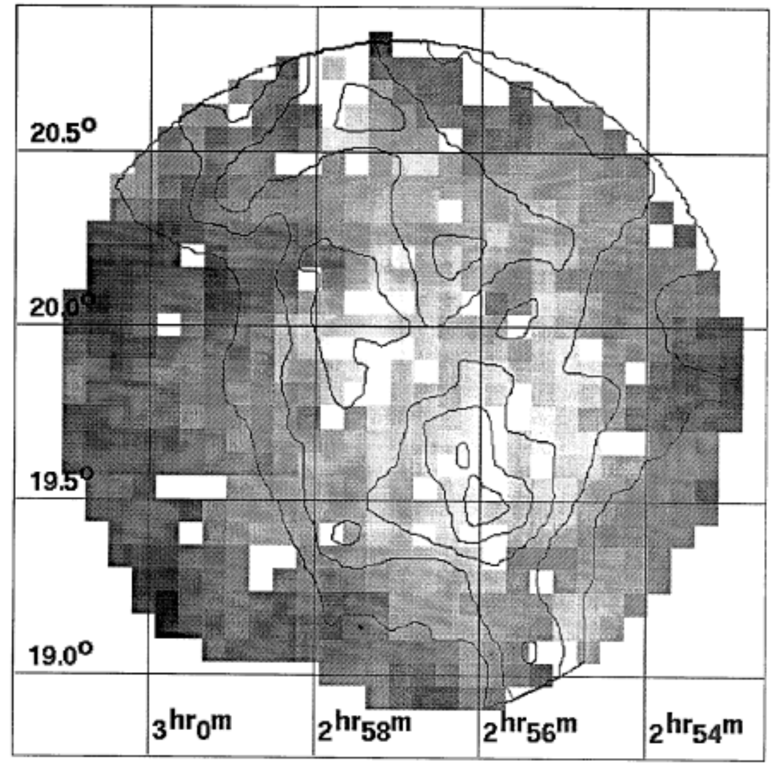
Shape reflects anticorrelation of B or C_L and n_H!



NORTH POLAR SPUR
NGP
LOOP I?
300
120
SGP
NORTH POLAR SPUR
NGP
330
150
LOOP I?
SGP
180
GALACTIC PLANE
MONOGEM
VOID
270
90
LOOP I?
CYGNUS
0

Scaling the LHB



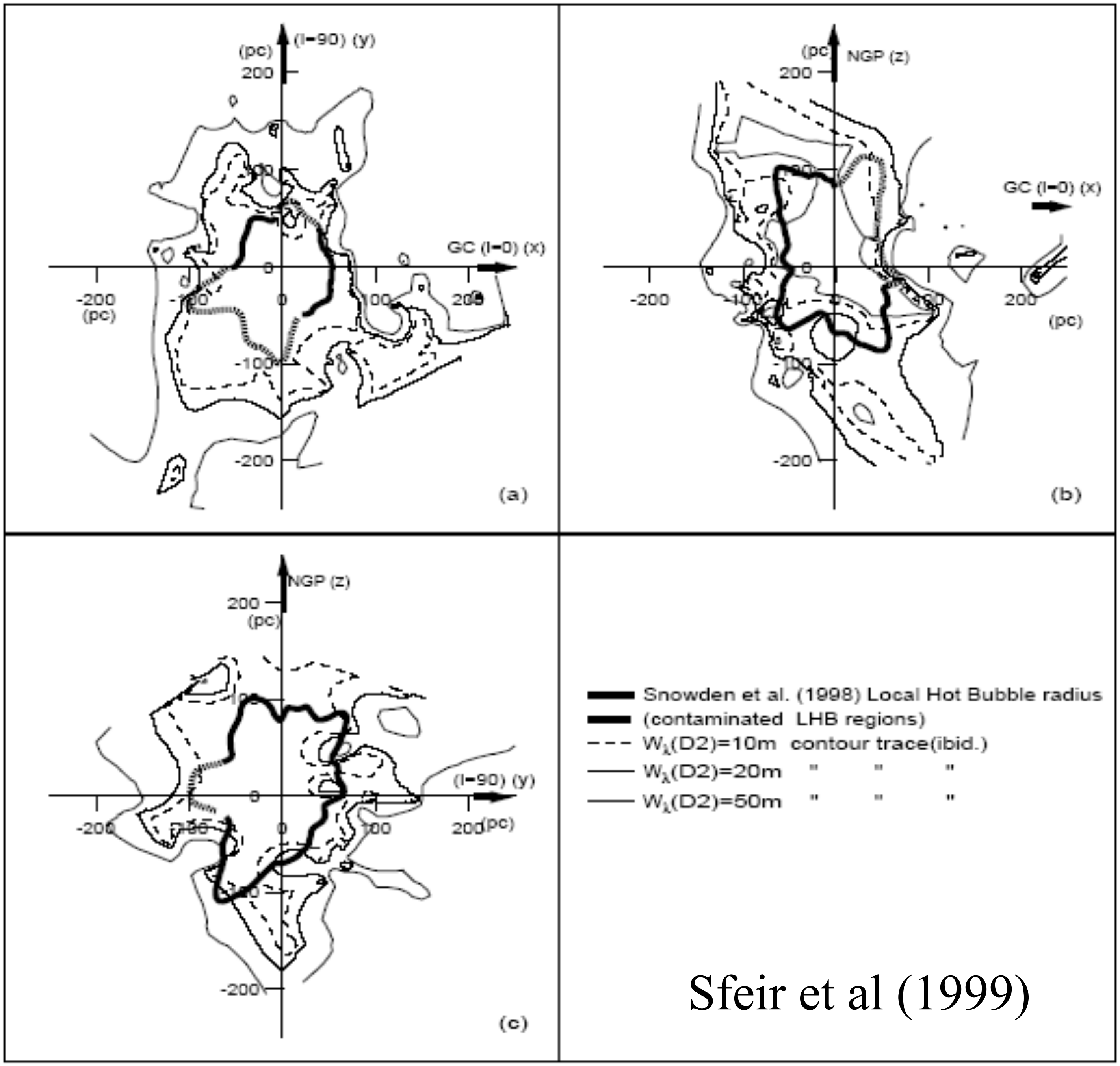


MBM12 shadows the LHB emission

R=60-90 pc $I_L=347\times10^{-6}$ counts/s/arcmin^2 (R12)

Other MBM clouds w/o shadows place consistent limits

Scaling does not significantly violate Sfeir boundary

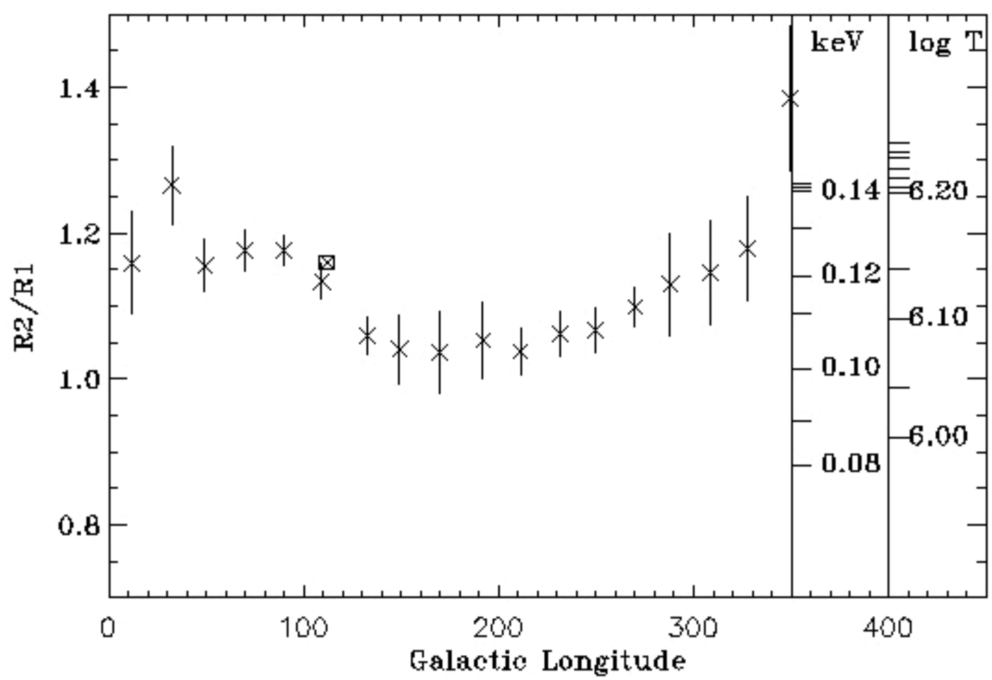


Sfeir et al (1999)

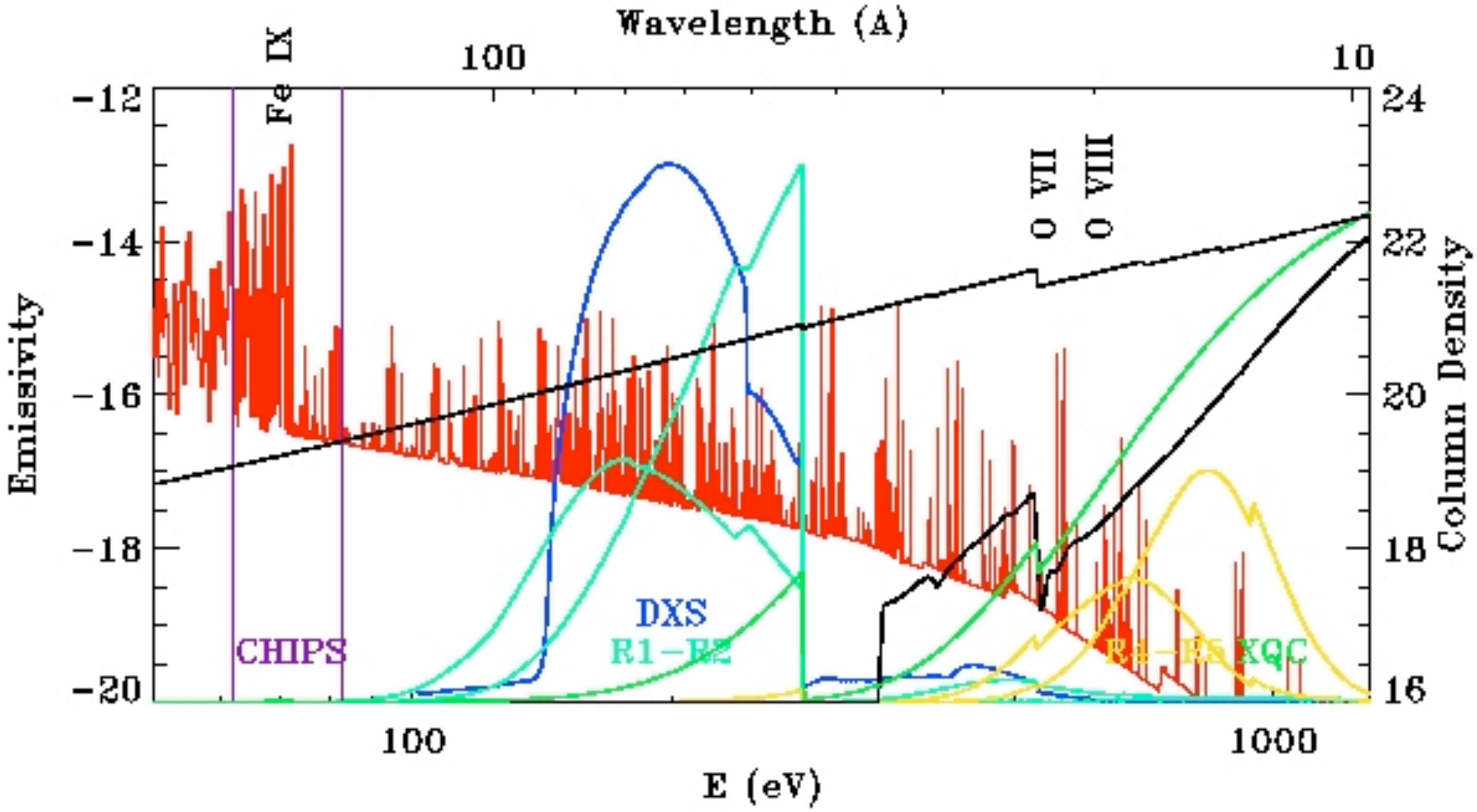
Isolating the Local Component

What else do we learn?

- There is a gradient in the emission (Snowden et al 1990)
  - B/C is higher towards l=168°, lower towards G.C
  - Temperature is lower towards l=168° (log T=5.9 vs. 6.0)
- Similar result from shadow analysis
  - logT=6.02 vs. 6.13

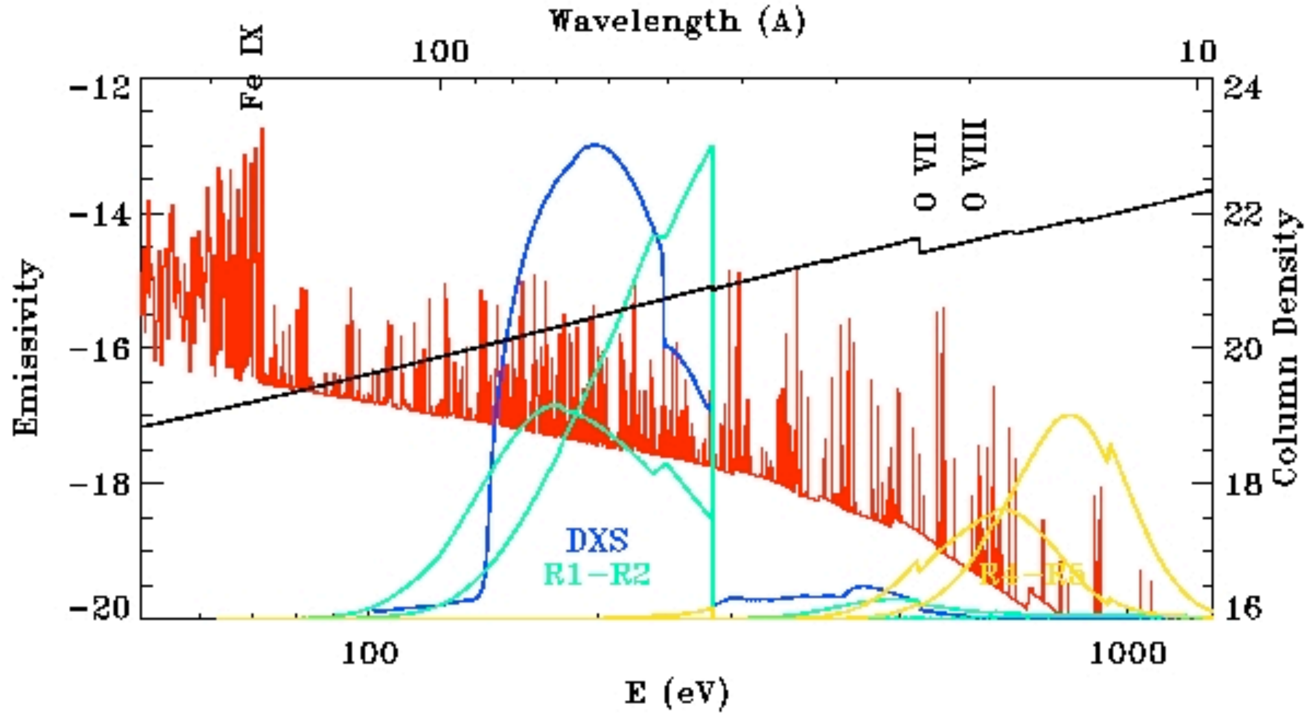


Spectroscopy



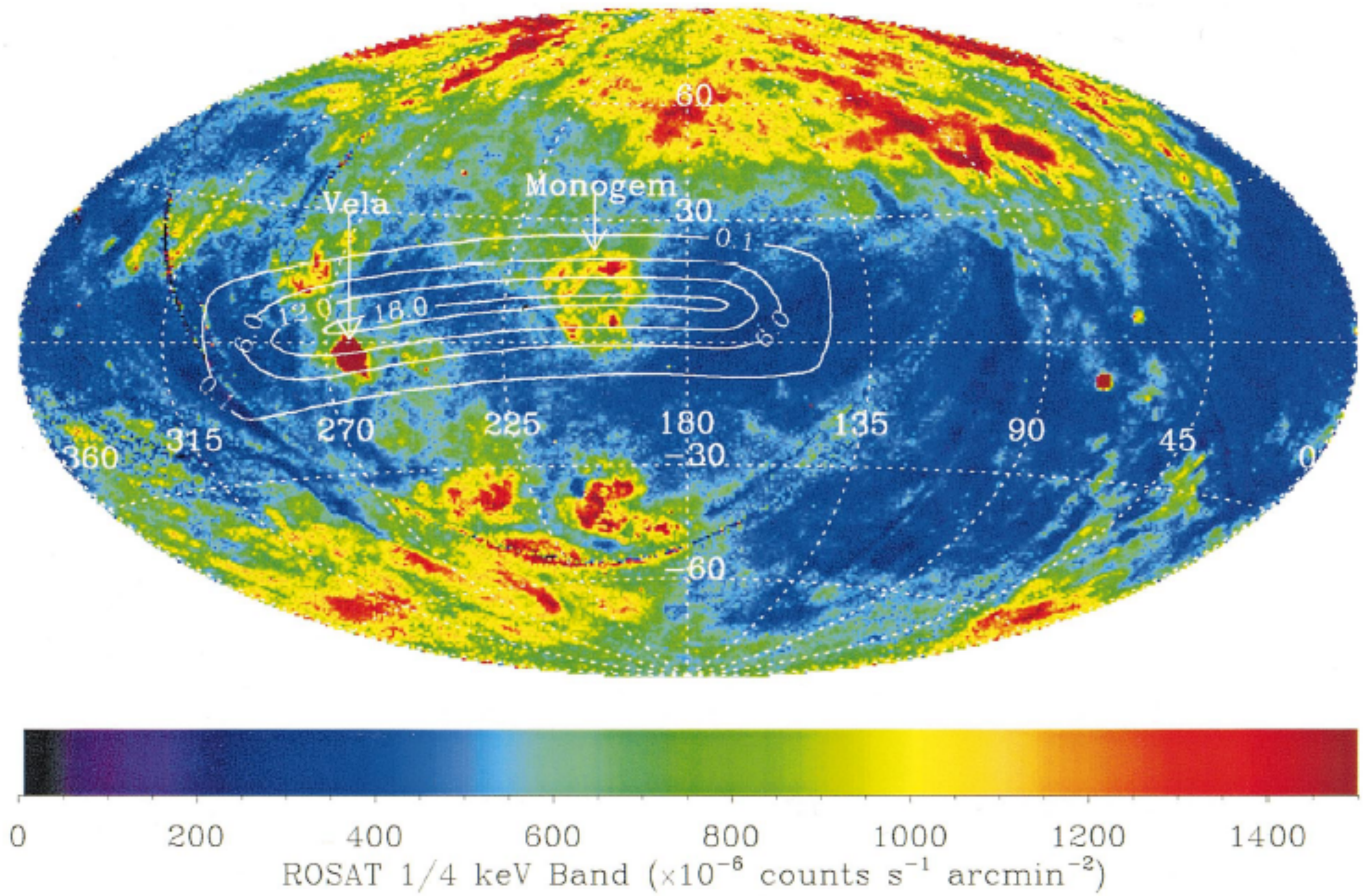
Spectroscopy:DXS (Sanders 2001)

- 148-295 eV with a resolution of 4 eV



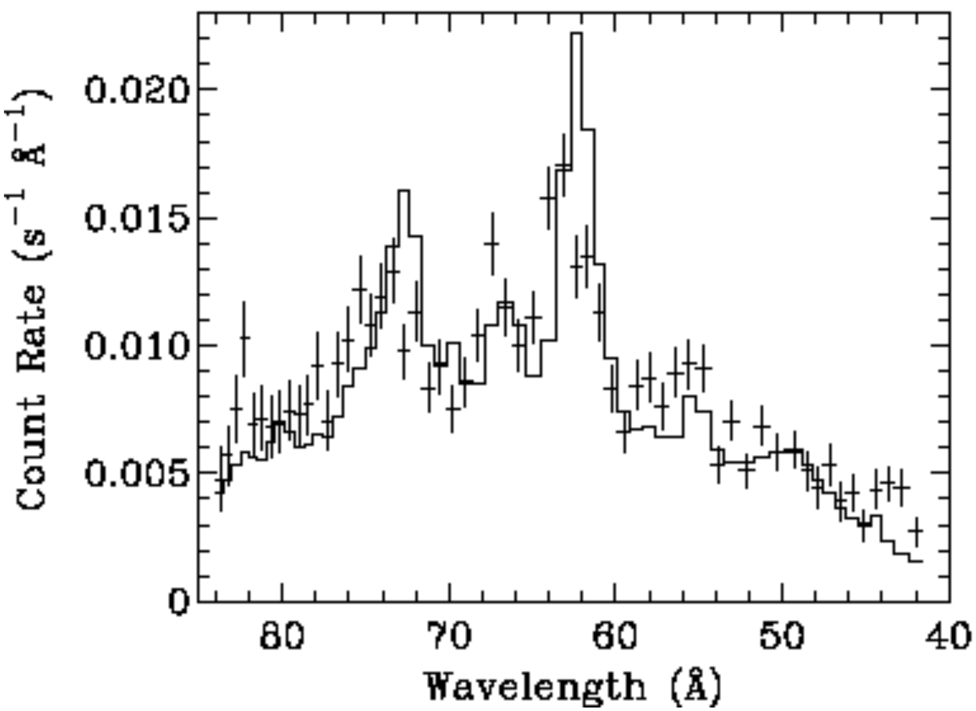
Spectroscopy:DXS (Sanders 2001)

- 148-295 eV with a resolution of 4 eV
- 0.26 sr FOV



Spectroscopy:DXS

- Lines! → thermal or quasi-thermal
- R&S model (CIE) does not work
- R&S model with Mg, Si, Fe adjusted down by 3X
- Non-CIE models worked no better



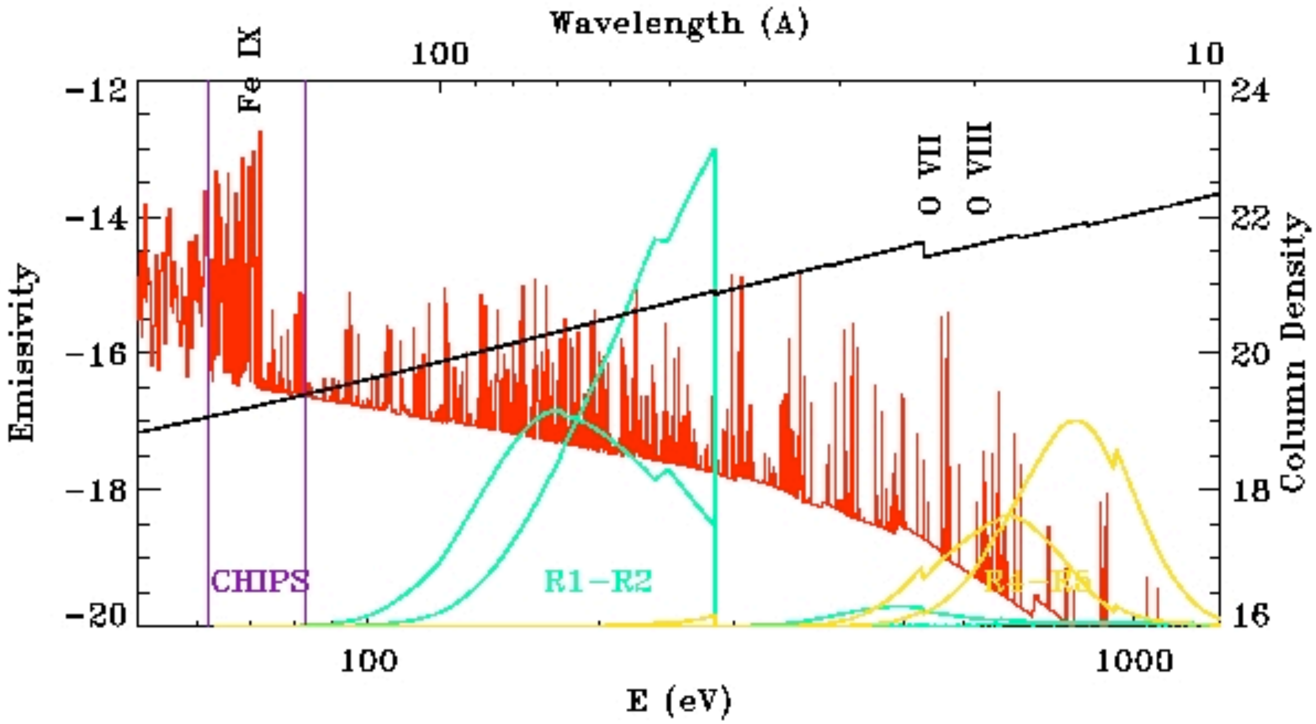
Spectroscopy:DXS

Potential Problems:

- Bad or missing atomic data
- Non-CIE parameter space is large
- Complex line of sight
  - Spans a range of different R2/R1
  - Background model
  - Absorption due to cavity wall

Spectroscopy:CHIPS (Hurwitz 2005)

- 82.65-61.99 eV at a resolution of 0.6eV



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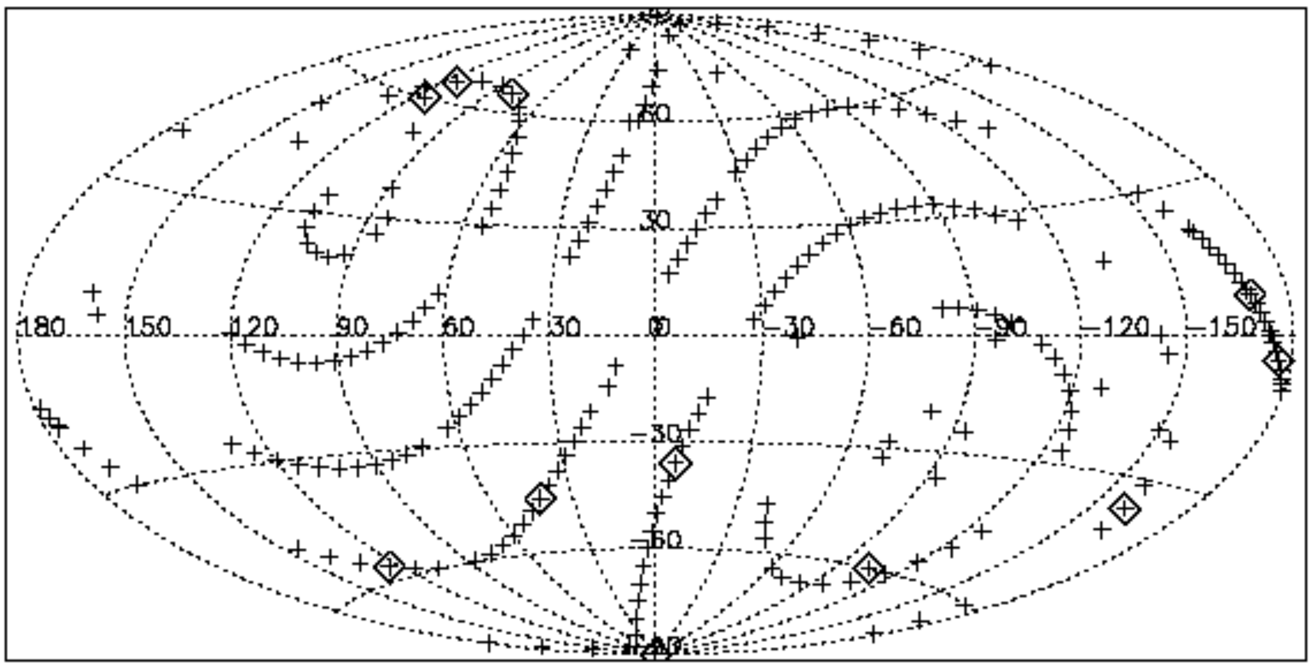

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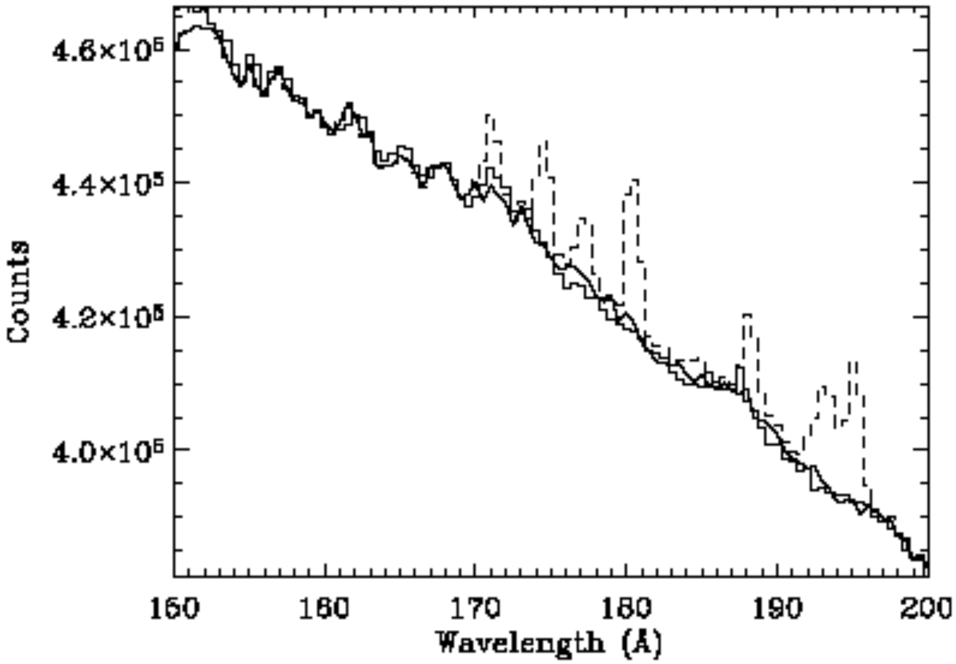
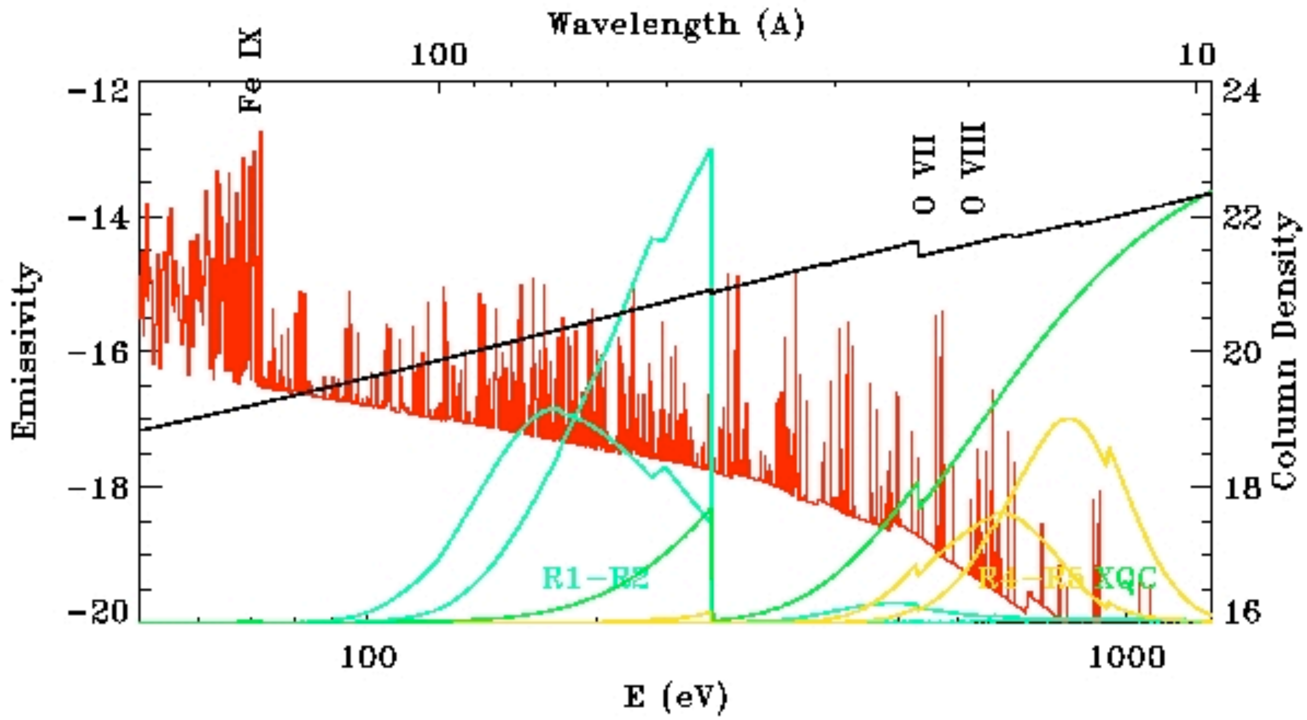


Fe IX is 6 LU (photon/cm^2/s/sr)

- Best fit $10^{5.8}$K, EM=0.00014 cm^{-6}pc (solar abund)
  - $10^{6.0}$K, EM=0.00042 cm^{-6}pc at 1/3 solar
  - EM~0.0039 cm^{-6}pc (ROSAT) values requires 1/16 solar
- Consistent with WFC(?) EUVE (Jelinsky et al. 1995)
- Marginally consistent with Wisc. data (Bellm & Vaillancourt 2005)

Spectroscopy:XQC (McCammon 2002)

- 60-1000 eV at a resolution of 9eV
- FOV~1 sr



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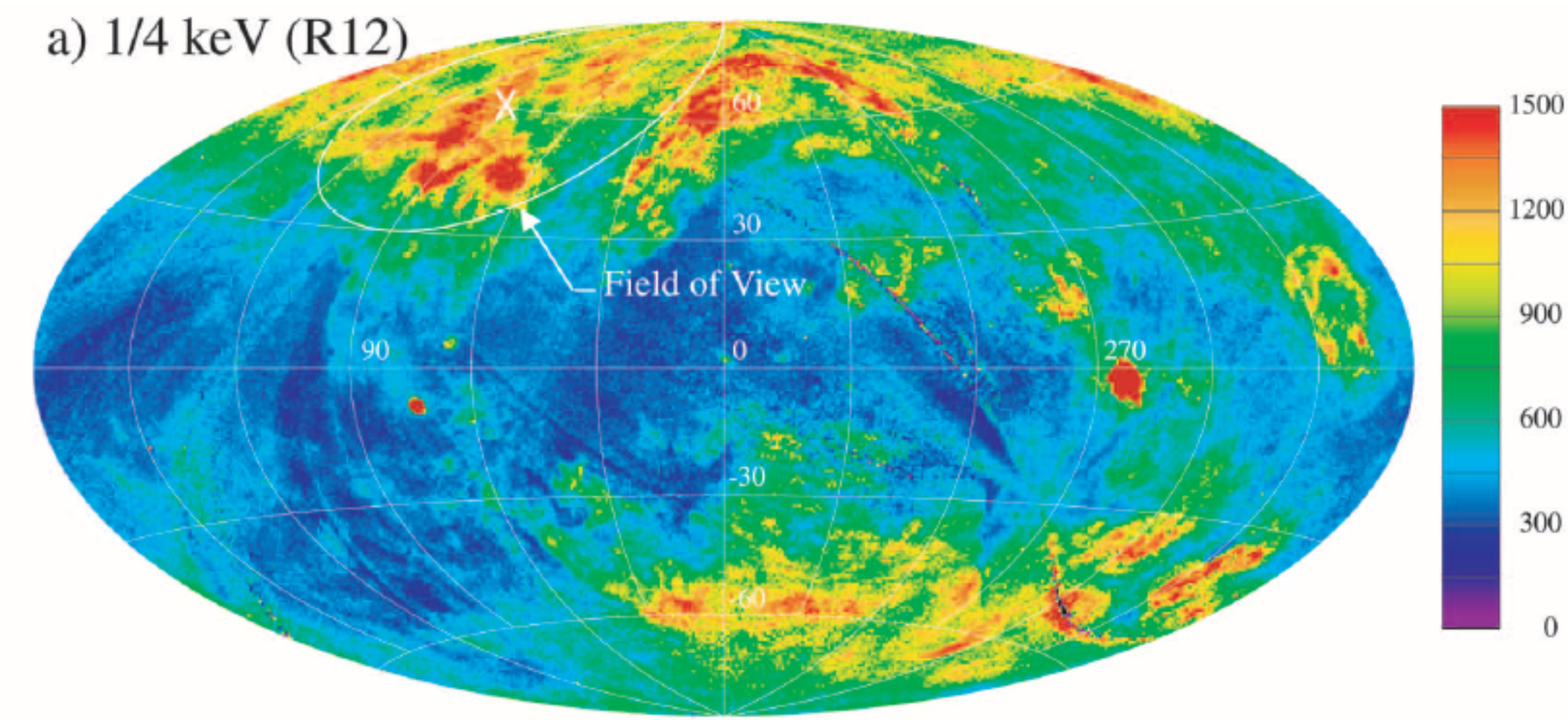
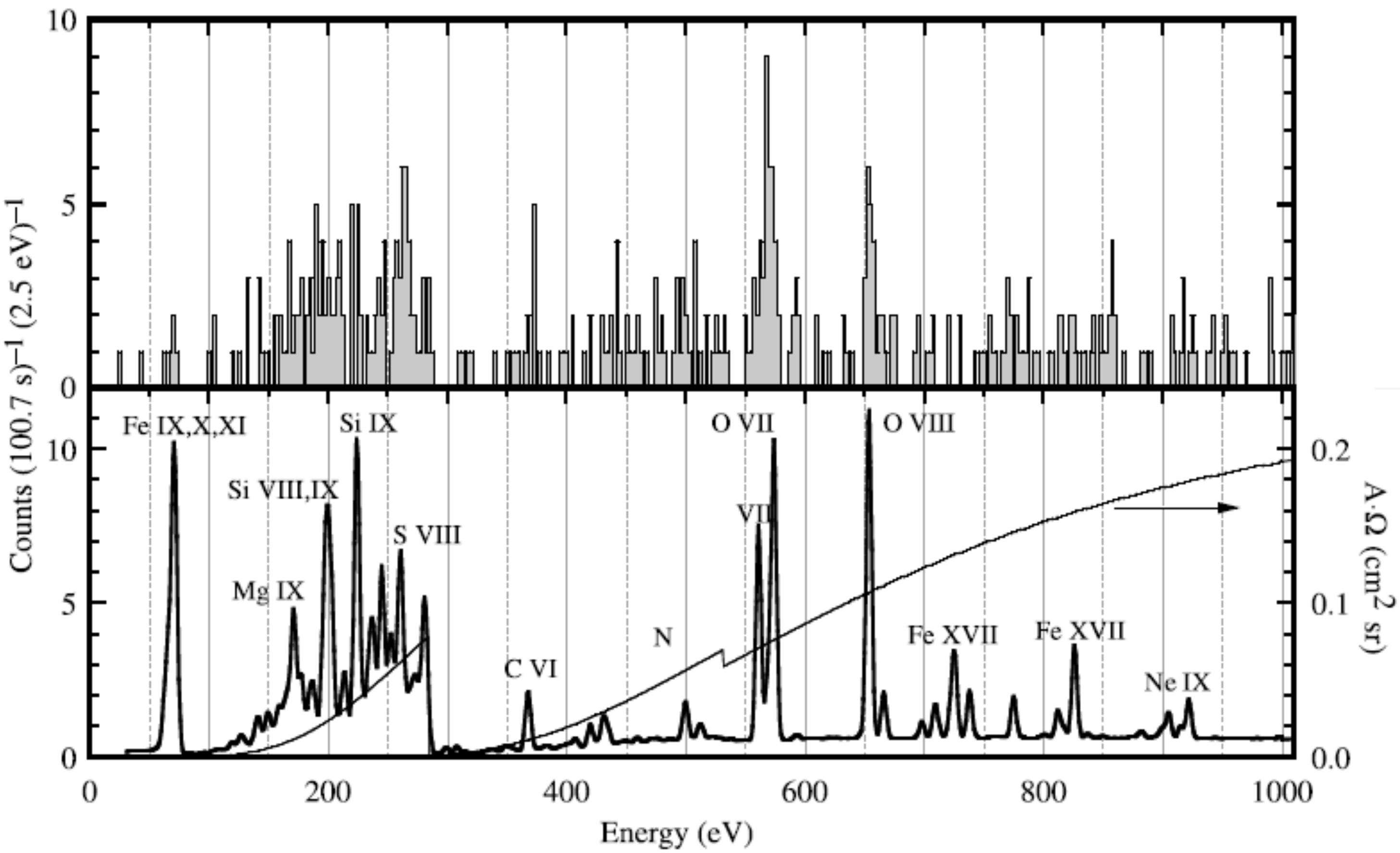


Spectroscopy:XQC (McCammon 2002)

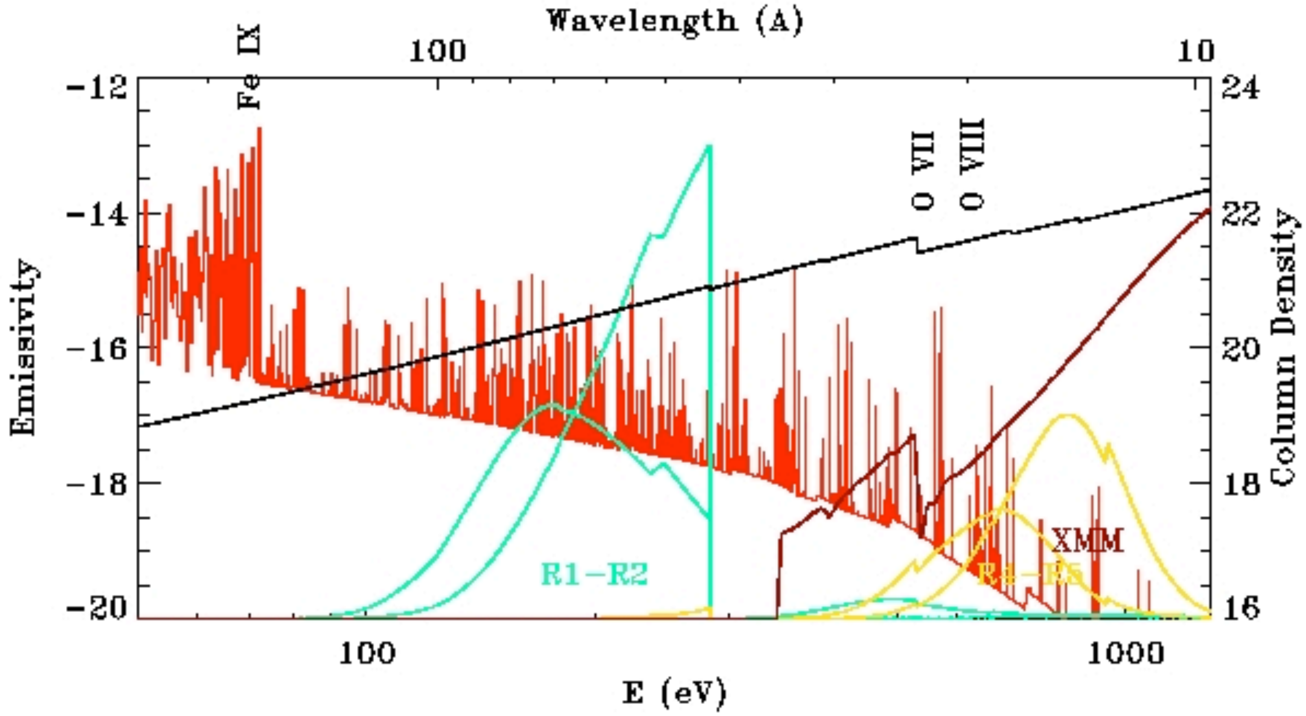
Spectrum includes both LHB and Galactic Halo (but not at Fe IX)

FeIX, FeX, FeXI = 100±50 LU, but bright CHIPS region

Marginally consistent



Chandra/XMM/Suzaku



- Resolution of 40 eV at 500 eV
- Need higher n_H to block non-LHB emission (5×10^{21})

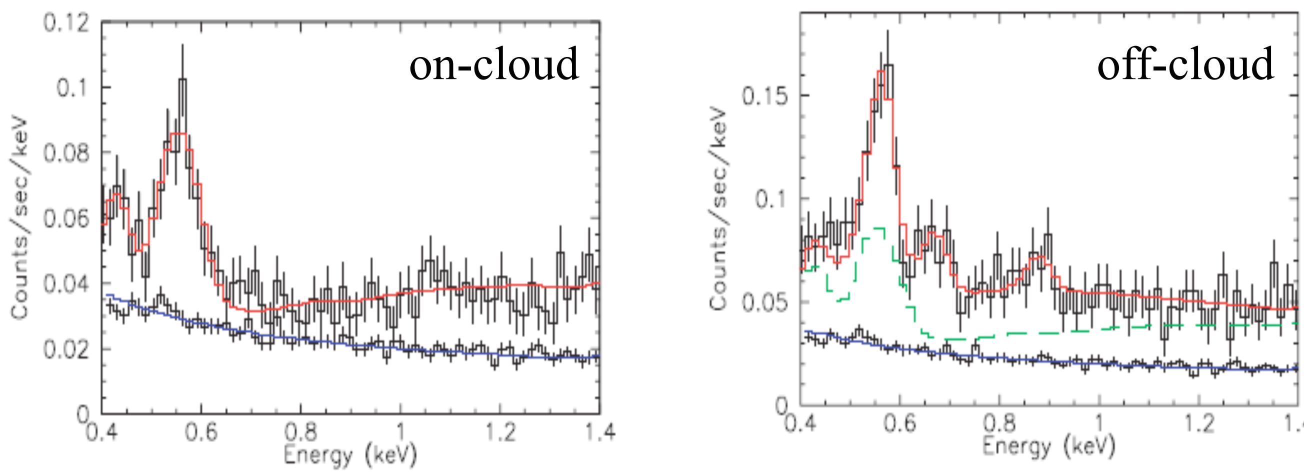
  Or model transmission of background spectrum
- Pessimist: measuring only high-E tail of LHB
- Optimist: measuring OVIII, OVII, & OVI (FUSE)

Chandra/XMM/Suzaku

Object	n_H	Instr.			Log(T)	OVII (LU)	OVIII (LU)	Flare/ SWCX
MBM12	3-8e21	Chan	Smith et al			1.75±0.55	2.34±0.36	f/major
MBM12	3-8e21	XMM	Freyberg&Breits.		6.17			f/major
MBM12	3-8e21	Suz	Smith et al	on/off	<6.22	3.5	0.25±0.1	-/minor
Mag	2.9e21	XMM	Snowden			2.7±0.4	0.39±0.17	-/minor
MBM20	2e21	XMM	Galleazzi et al	on/off	6.04-6.08	3.89±0.56	0.68±0.24	f/minor
MBM20	2e21	Suz	Galleazzi et al					
Filament	9.6e20	XMM	Henley et al	on/off	6.06-	3.4±0.5	<1.0	f/minor
Filament	9.6e20	Suz	Henley&Shelton	on/off	5.94-6.00	1.1±1.1	1.0±1.1	-/some
L=111°	1e20	XMM	Kuntz&Snowden		6.06-6.12	1.75±0.7		-/minor

- All use ROSAT to normalize
- The lower the n_H, the easier to swap flux from foreground to background
- Strongly model dependent
- Sensitive to assumed abundances

Chandra/XMM/Suzaku

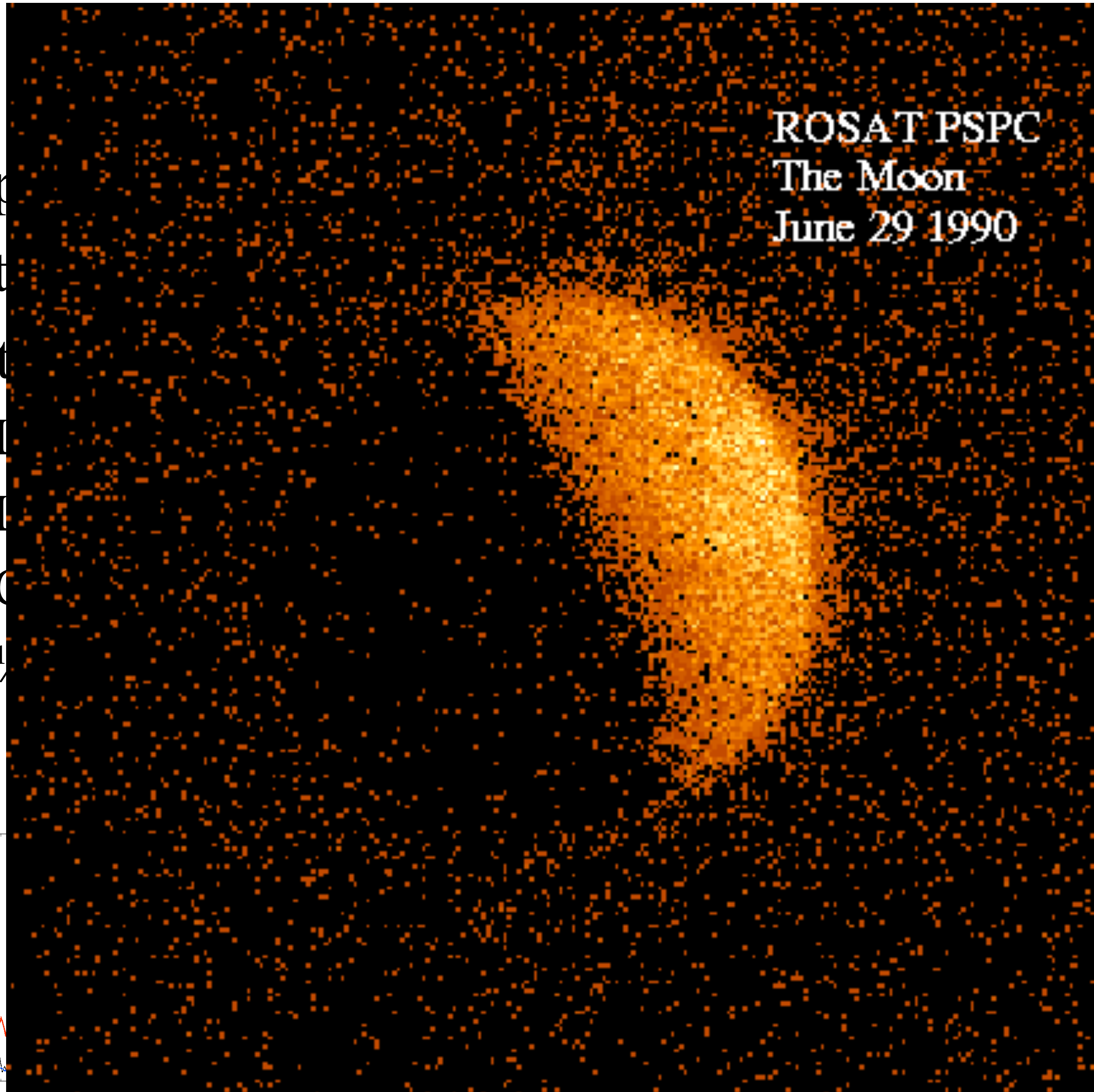


Smith et al (2007)

Suzaku observation of MBM12

- Measure of OVII and limit of OVIII → limit on T (kT=0.146 keV)
- Measure of OVII and T (10^6K) → emissivity → overpredicts R12 by 3X
  - Depleted abundances
  - Out of equilibrium (variation in OVII, gradient)
  - OVII is just too high (Koutroumpa 2008; SWCX)

- Exp
- Ext)
- Det
  - I SS
  - I nar
  - C)
  - 1



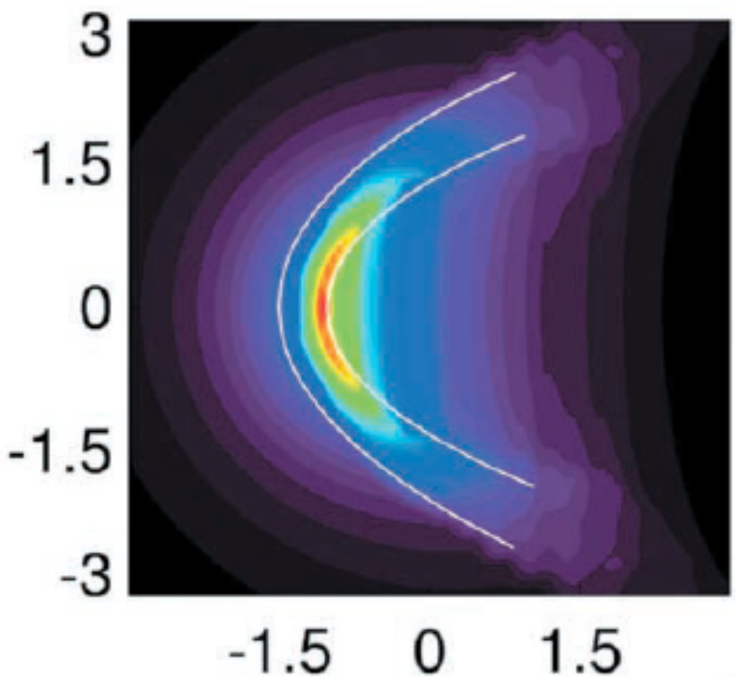
SWCX

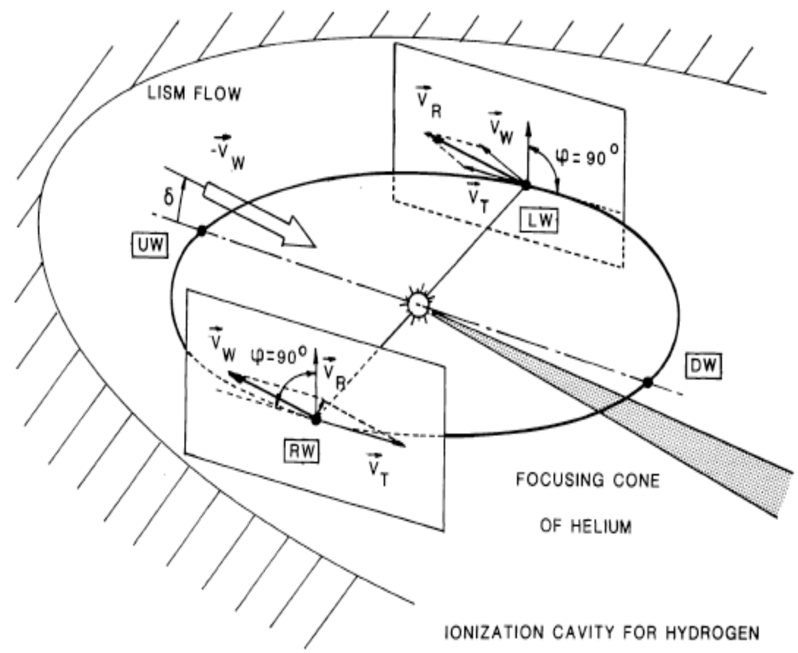
Local – highly time variable, strongly look-direction dependent

- Magnetosheath
- Exosphere
- Local ISM/local heliosphere (~few a.u.)

Non-local – only slowly variable, but look-direction dependent

- Remainder of heliosphere
- Heliopause



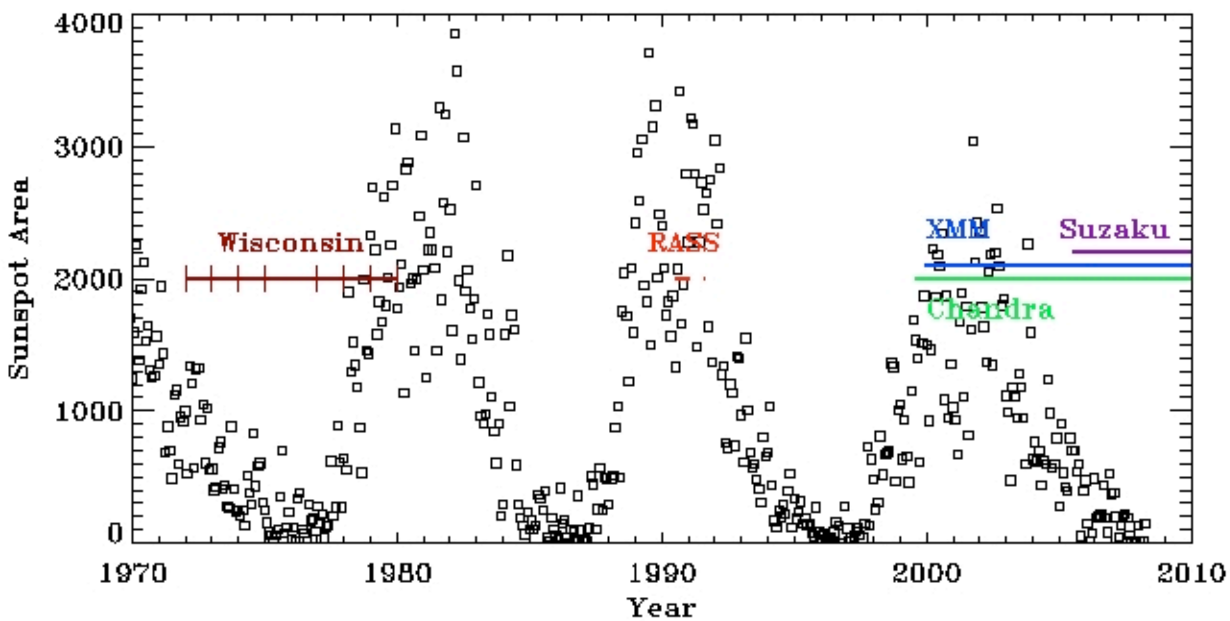


SWCX

Observed=LHB+helio(t)+exo(t)+mag(t)

Observed=LHB+min(helio)+(helio(t)-min(helio))+exo(t)+mag(t)

RASS LTEs



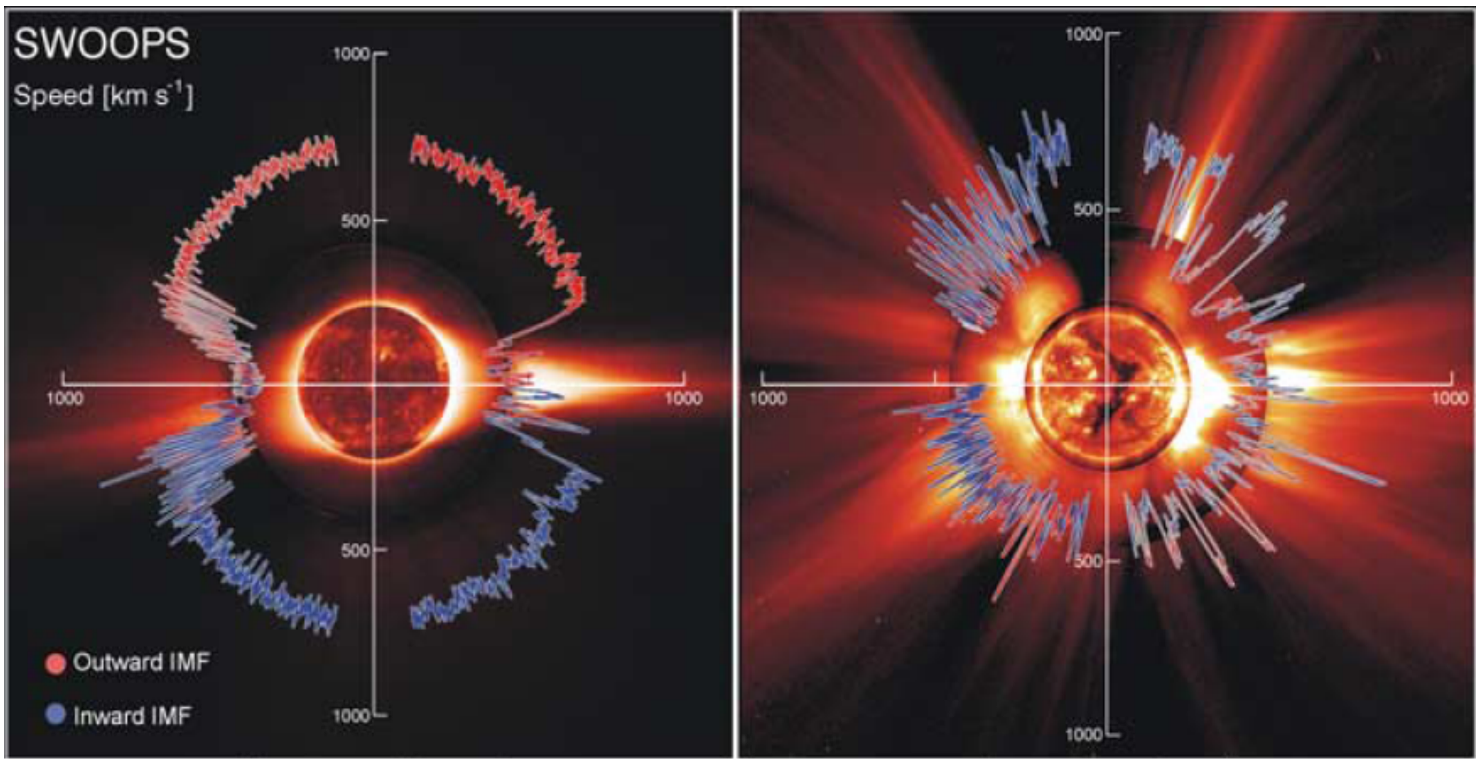
SWCX

Observed=LHB+helio(t)+exo(t)+mag(t)

Observed=LHB+min(helio)+(helio(t)-min(helio))+exo(t)+mag(t)

RASS LTEs

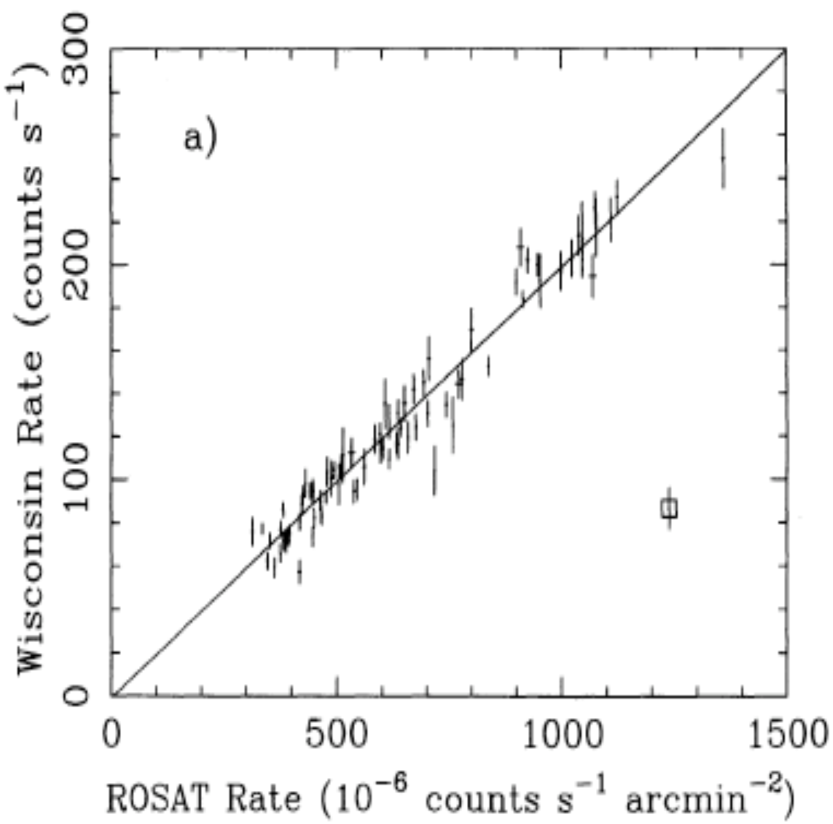
RASS and Wisconsin surveys should have very different min(helio) contributions



McComas et al 2003

SWCX

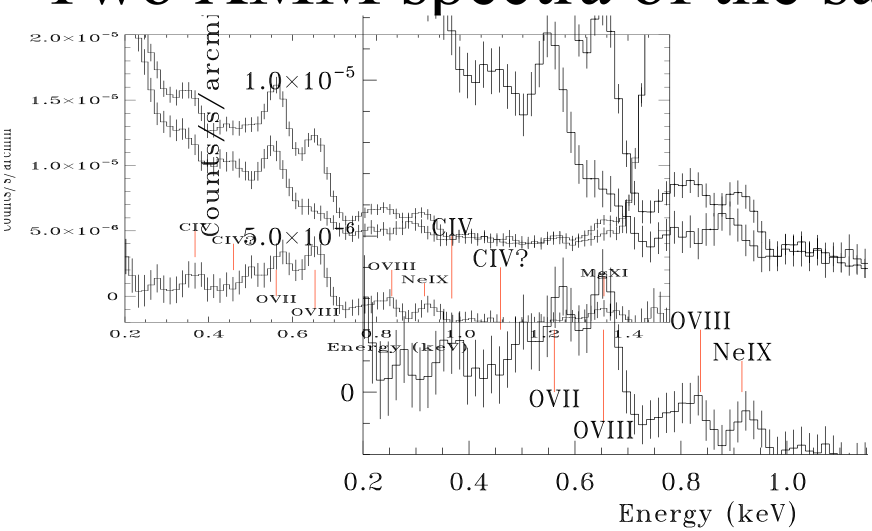
- No offset between RASS R12 and Wisconsin C
  - Total heliospheric SWCX small, or
  - Total heliospheric SWCX very stable

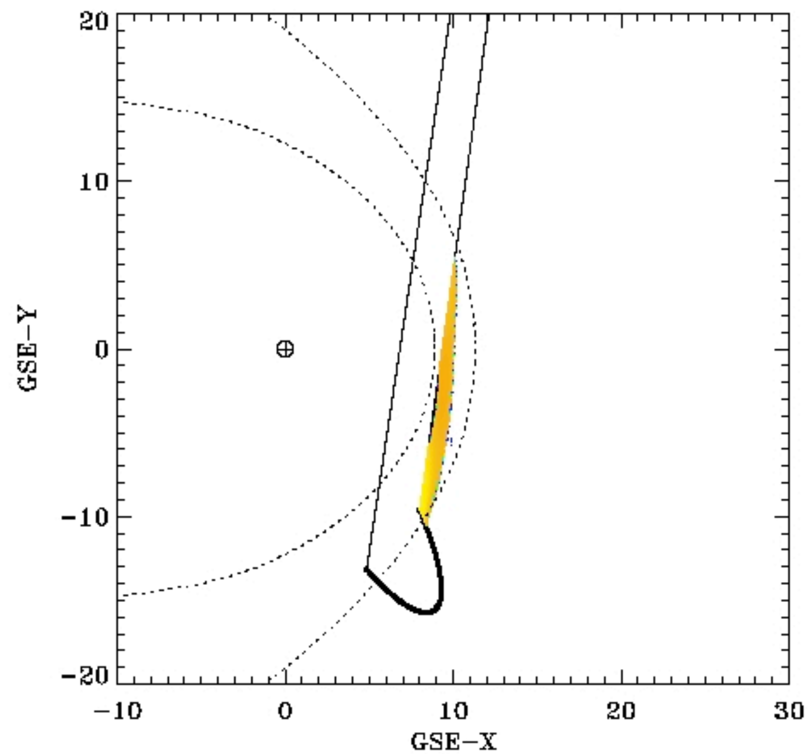


Snowden et al.

SWCX & Spectroscopy

Two XMM spectra of the same region: HDFN



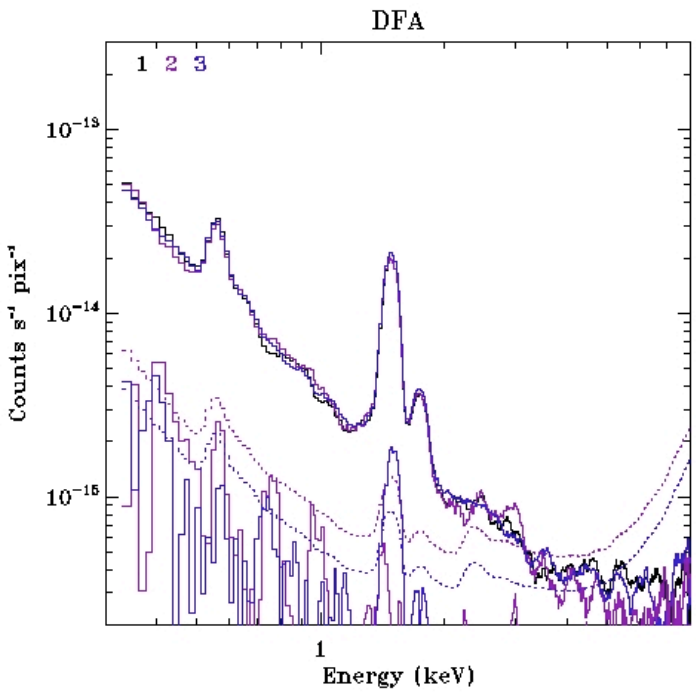


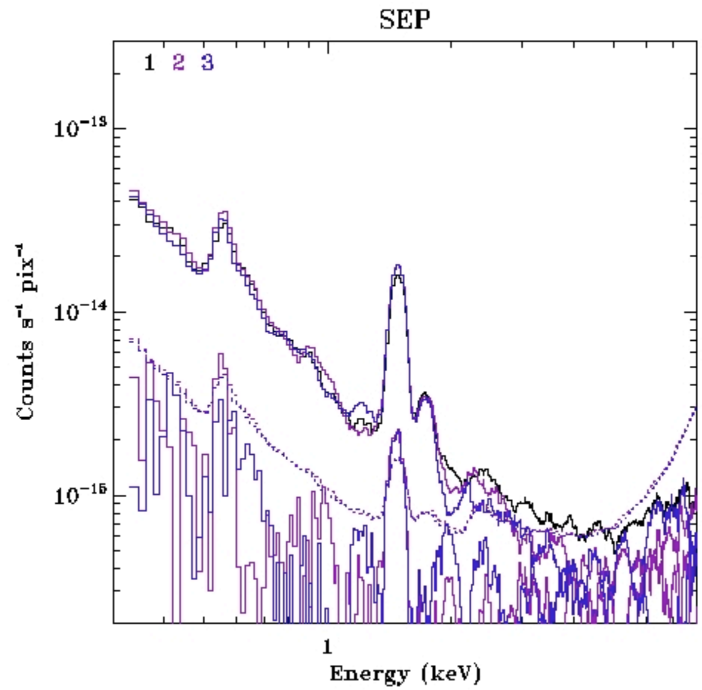
•SWCX particularly strong in the prime diagnostic lines OVII and OVIII
•Collier et al. (2007) and Koutroumpa (2008) agree on non-magnetosheath

SWCX & Spectroscopy

Extend the same method to the XMM archive (Kuntz&Snowden)

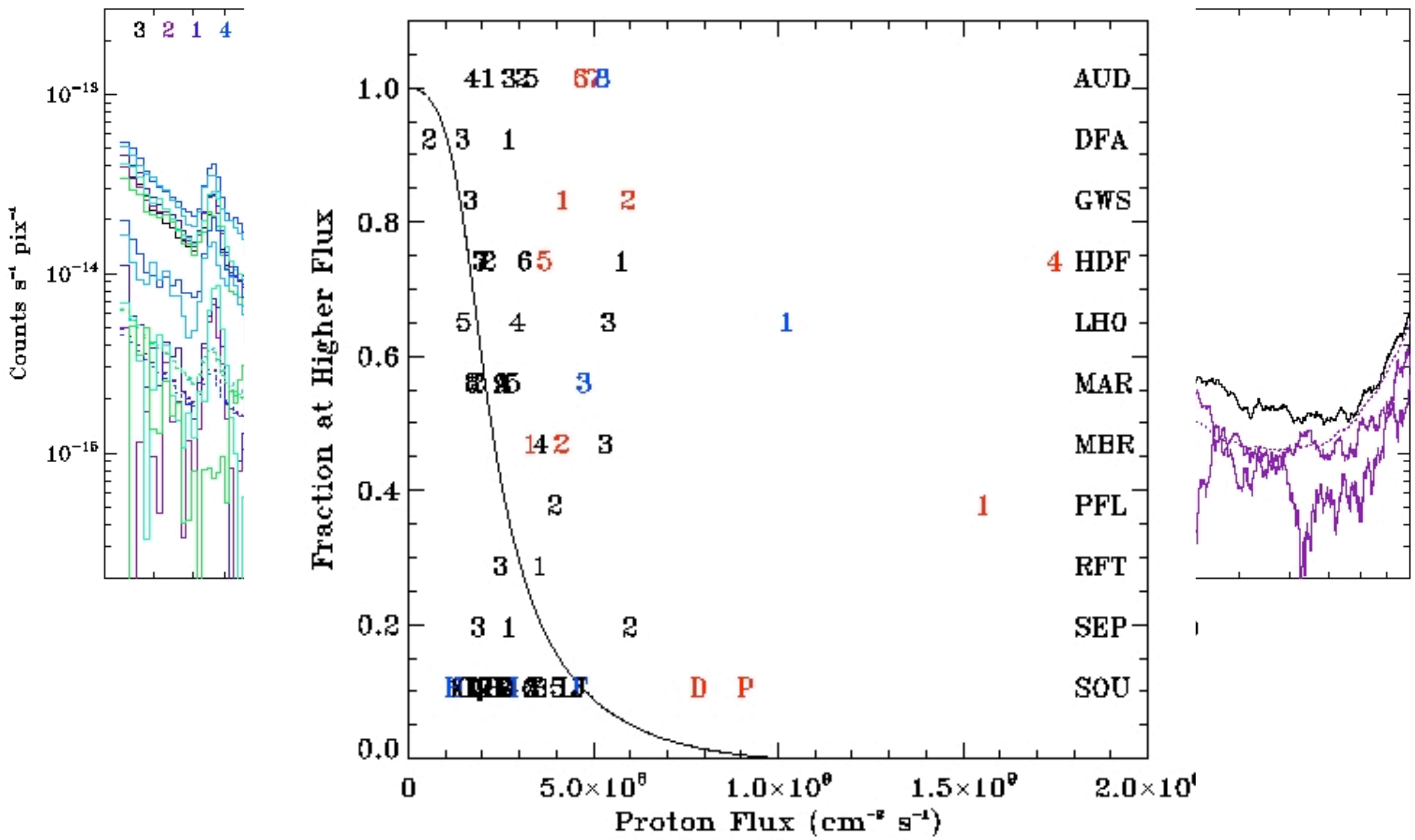
- Multiple observations of the same blank field
- Correlate changes in OVII and OVIII with SW and geometry





For most observations Δline ≤σ

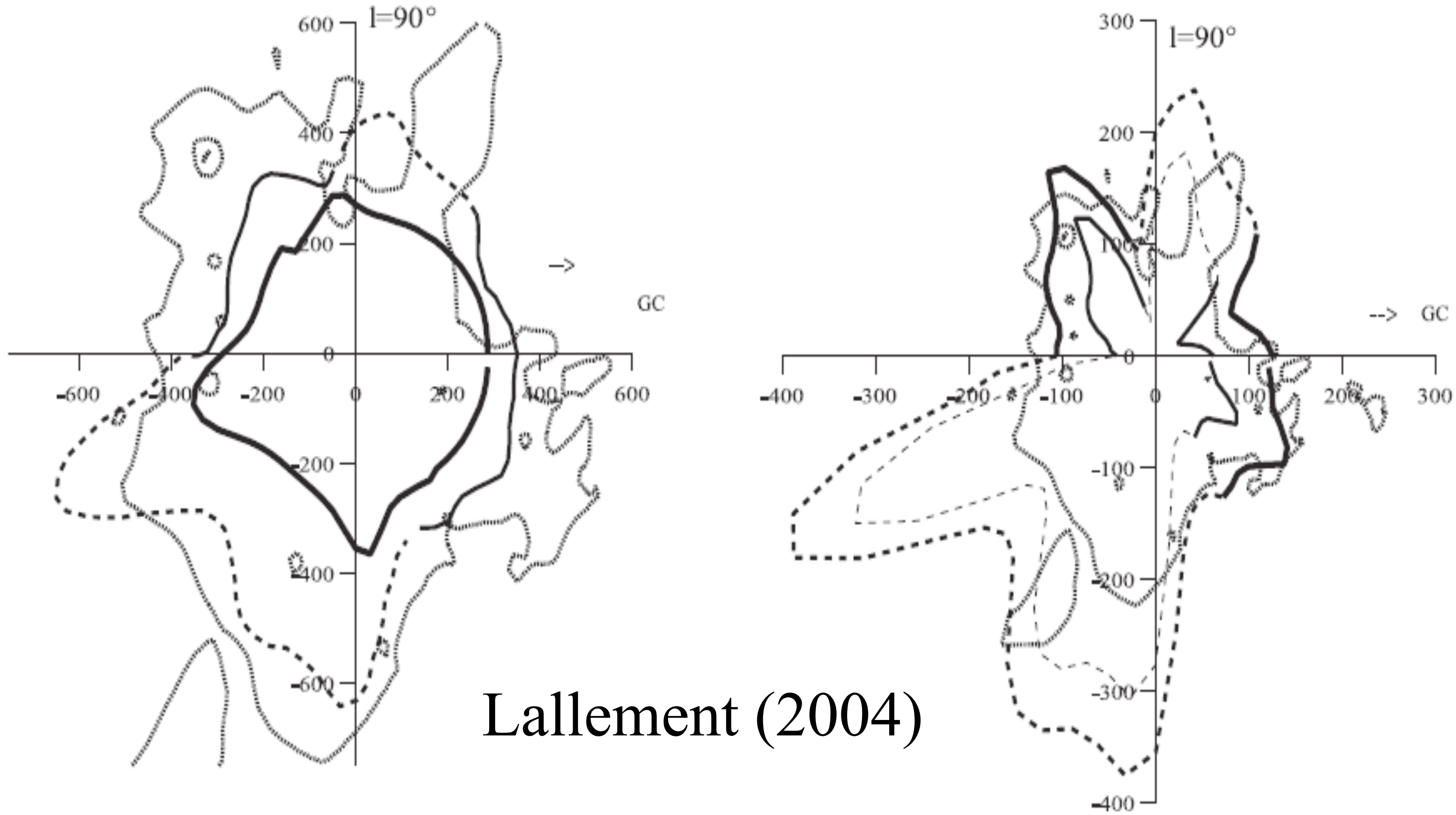
SWCX & Spectroscopy



1. Looking near nose with quiescent SW → Δline insig.
2. Looking through flanks w/ high SW →Δline large
3. Large Δline w/ low SW → SW fronts missed by ACE

SWCX & LHB

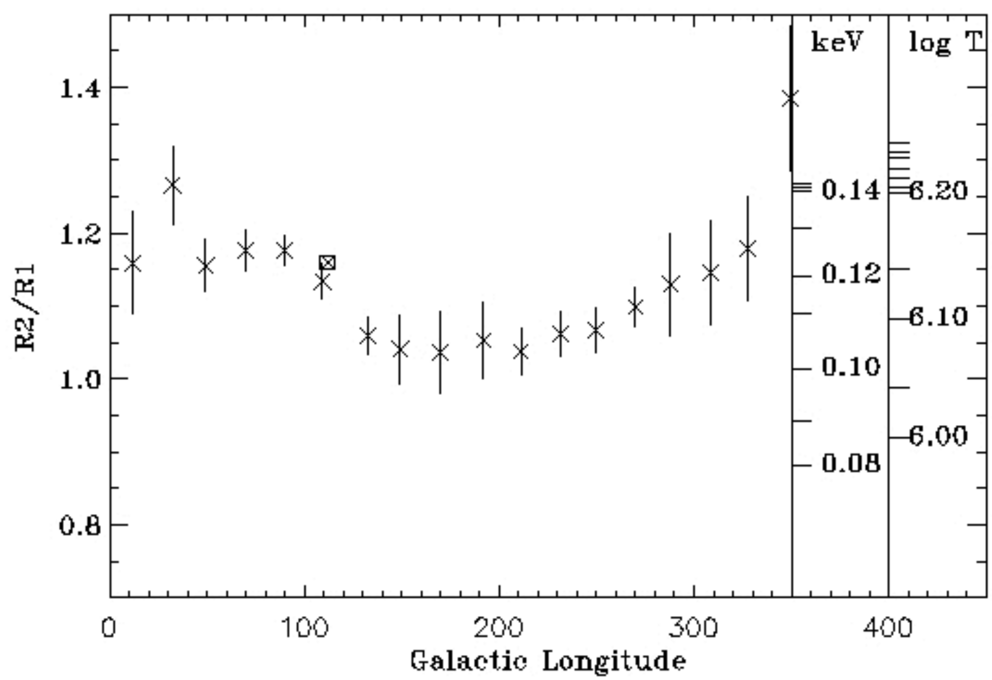
- Flux – reduced I = fI → n = n√f and P = P√f
- Size – no change
- Shape



Lallement (2004)

SWCX & LHB

- Flux – reduced I = fI → n = n√f and P = P√f
- Size – no change
- Shape – may match the Local Cavity, may not
- Gradient – dipole orientation is same as ISM wind direction
- Temperature – unknown



SWCX & LHB

- DXS – effected only by heliospheric SWCX
- CHIPS – parent species most abundant in SW, but…
  - Does this make the problem worse?
- XQC – the slow low density SW favors FeIX
- XMM – observation geometry is important!
- SXG!

The Once and Future LHB

LHB Studies should return to their roots: B&Be bands

- Maximize the local/minimize the distant emission
- Lower column density clouds to be used as shadowing targets

But…

- Energy region for which atomic data more poorly known